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A

TREATISE

ON THE

STEAM-ENGINE

FROM THE SEVENTH EDITION

OF THE

ENCYCLOPÆDIA BRITANNICA.

BY

JOHN SCOTT RUSSELL, M. A., F. R. S. E.

VICE-PRESIDENT OF THE SOCIETY OF ARTS
FOR SCOTLAND, &c. &c. &c.

NEW EDITION, REVISED AND CORRECTED.

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PREFACE

TO THE SECOND EDITION.

THE favourable reception which this Treatise has met with, from the public having exhausted the first impression, and a Second Edition having become necessary, considerable pains have been taken to render it still more deserving of patronage. The detailed accounts formerly given of some of the more obsolete engines have been abridged; and the descriptions of many other machines corrected, simplified, and made to agree better with the diagrams and plates. Regard has also been had to recent improvements.

What relates to the Governor has been materially altered; and a simple method has been proposed which it is hoped will effectually do away with those incessant vibrations of the balls, which, it is well known, have hitherto so much impaired the efficiency of that important appendage of the steam-engine.

Some of the objections and reasonings against rotatory engines have been a little moderated; not that I have anything to urge in their favour; but because, in the absence of perfect certainty, it seems premature to denounce every attempt in that department as absolute folly.

Only a few years have elapsed since it was as confidently maintained that steam would never impel a ship across the Atlantic.

But the alterations and additions are too numerous and many of them too trivial to be all noticed here. The footnotes, however, after page 17 are all new. Perhaps it is still necessary to crave the same indulgence from the reader as is done in the preface to the first edition.

It may be proper to add that various other particulars connected with the subject will be found in the articles Steam and Steam Navigation; which, besides forming parts of the Encyclopædia, have been published together in a separate volume. The like may be said of the article Railways. It is also principally in these departments that the more recent improvements connected with steam have taken place. Descriptions of the latest will be found in the scientific journals.

HENRY MEIKLE.

EDINBURGH, *April* 1846.

PREFACE

TO THE FIRST EDITION.

THE articles STEAM and STEAM-ENGINE in the former edition of the Encyclopædia Britannica were written by Dr ROBISON, who had been the early companion of JAMES WATT, and thus became the historian of his achievements, the expounder of inventions of which he had closely watched the origin and progress. His articles are distinguished by that clearness of conception, closeness of reasoning, and gracefulness of style, which entitle him to be ranked among the soundest and most accomplished of those authors who have contributed to the advancement of mechanical science. These articles have long formed the standards of our knowledge, and are still the fountain-head to which we resort for information. To Sir David Brewster we are indebted for the publication of certain contributions to these original articles which have enhanced their value: to his edition of Dr Robison's works, Mr Watt himself undertook to contribute notes and additional matter, and thus became at once the historian of his own inventions, and the commentator on the writings of his early friend.

Thus, the friendship of these two distinguished individuals, commencing with the warmth of youthful companionship, and continuing through all the vicissitudes of their lives, is embalmed in these their joint contributions. It appeared to the writer of these pages, that he could not better discharge the duty devolved upon him, in accepting the responsibility of the articles Steam and Steam-Engine, in the seventh edition of the Encyclopædia Britannica, than by retaining as much of those original contributions of Robison and Watt as could consist with the present advanced state of knowledge and practical art. Considerable portions of them are, therefore, presented to the reader as they came from the pens of Robison and Watt, and to these valuable gems his own contributions serve only as the mere "setting" required to connect them with the now extensive structure of practical science.

In the joint lives and labours of Robison and Watt, we open one of the brightest pages of the "friendships of philosophy"—intellectual prowess was in them remarkably conjoined with the virtues and amiabilities of social life, and it is difficult to say, whether we more admire the philosopher, or love the man. Akin to these feelings appear to have been the sentiments with which through life they regarded each other. Fortunately, the records of these sentiments still exist in notices written by themselves. Robison's sketch of Watt is already before the public; but we have now the pleasure of presenting to our readers, a companion sketch of Robison drawn by Watt himself, which we owe to the kindness of Sir John Robison, and which in April 1805, was addressed by Watt to the widow of the friend of his youth.

Mr Watt's Sketch of Dr Robison.

"Our acquaintance began in 1756–7, (Mr Robison being then 17,) when I was employed by the University of Glasgow to repair and put in order some astronomical instruments bequeathed to the University by Dr Macfarlane of Jamaica—Mr Robison was then a very handsome young man, and rather younger than me. He introduced himself to me, and I was happy to find in him a person who was so much better informed on mathematical and philosophical subjects than I was, and who, while he was extremely communicative, possessed a very clear method of explaining his ideas. Between two young men of ardent minds engaged in similar pursuits, a friendship was soon formed, which has continued until death has deprived me of my friend, and has suffered no other interruption than what has been caused by our absence from each other, and the necessary attention to our respective duties in life. Soon after this, I settled as mathematical instrument maker in the College of Glasgow, and was favoured with Mr Robison's company until he left the college about the end of 1758, and went to sea—I believe in one of his Majesty's ships.

"During this period, he turned my attention to the steam-engine, a machine of which I was very ignorant, and suggested that it might be applied to giving motion to wheel carriages, and that for that purpose it would be most convenient to place the cylinder with its open end downwards, to avoid the necessity of using a working beam. The latter idea he had published some time before in the *Universal Magazine.*—In consequence, I began a model with two cylinders, of tin plate, to act alternately by means of a * * * acting on two pinions attached to the axles of the wheels of the carriage; but the model being slightly and inaccurately made, did not answer expectation. New difficulties presented themselves; both Mr Robison and myself had other avocations requiring our attention, and neither of us having then any idea of the true principles of the machine, the scheme was dropped. I however went on with some detached experiments on steam, until 1763, when I set about the matter more seriously, and discovered the principles upon which my improvements on the steam-engine were founded."

Beside this we place the following extract from Arago's Eloge of Watt; being—

DR ROBISON'S SKETCH OF YOUNG WATT IN HIS WORKSHOP.

"When I was as yet a young student, I had the vanity to think myself a pretty good proficient in my favourite studies of mathematical and mechanical philosophy, and on being introduced to Watt, was rather mortified at finding him so much my superior. Whenever any of us stumbled on a difficulty, we went to Watt; he needed but to be prompted; every thing became to him the beginning of a new and serious study, and we knew that he would not quit it till he had either discovered its insignificancy, or made something of it. . . . On one occasion, the solution of a problem seemed to require the perusal of Leupold's Theatrum Machinarum—and Watt forthwith learned German; at another time, and for a similar reason, he made himself master of Italian. . . . when, to the superiority of knowledge which every man confessed, is added the *naive* simplicity and candour of Mr Watt's character, it is no wonder that the attachment of his acquaintance was strong. I have seen something of the world, and am obliged to say, I never saw another such instance of general and cordial attachment to a person whom all acknowledged to be their superior. But this superiority was veiled under the most amiable candour and liberal allowance of merit to every man—Mr Watt was the first to ascribe to the ingenuity of a friend, things which were very often nothing but his own surmises, followed out and embodied by another. I am well entitled to say this; having often experienced it in my own case."

Below this sketch Mr Arago has written a note, to which we shall every one subscribe:—"It is difficult to determine whether the honour of having uttered these last words is not as great as that of having inspired them"—and, with both sketches before us, we are equally left in doubt whether each were not fully entitled to all the encomiums his friendship has passed on the companion of his youth and the unchanged friend of declining age.

In the present articles, it has been the author's aim to add to all that Robison had originally said of Watt's invention, what he would have required to add had he lived to witness its present extended use, its multifarious applications, its varied forms, its modifications in materials and construction. In all else—in principles, in useful effect—little has been added, though much has been changed since the machine came out of the hands of the original inventor. The author has to regret the inadequacy of his work to the design which he had formed, and its defects, even when compared with his own standard of excellence. Unfortunately the duties of a laborious profession allow him little leisure for literary exertions. He has however endeavoured to place before the reader, in a simple form, all the most important information which many years of research and of practical experience in a favourite subject, have placed in his possession; and the reader who is familiar with the subject will readily discover that he has read and thought for himself, and that his errors, if many, are at least his own. In one point he trusts he has facilitated the progress of the student. While giving the general reasoning of complex calculations, he has endeavoured to disembarrass them as much as possible of that parade of calculus which exhibits the author at the expense of the reader; and rather to present their results in that simple form in which alone great truths present themselves to those who thoroughly understand them. In treating an extensive subject in a limited space, he has also preferred to present general truths, rather than to enlarge upon minute details and multifarious definitions, which often lead the reader to imagine he understands a subject when he only remembers the technical phrases in which it is conveyed, having acquired nothing more than that species of mere word knowledge deplored by Bacon—

> "Qui voces artis habeant in promptu, etiam artes ipsas perdidicisse existimentur."

It is further necessary, that the intelligent reader who shall happen to compare these articles with any other treatises that may have recently appeared, should be apprized that a great part of them was written a considerable time ago, and that the commencement was actually in the press two years before the present date of publication; its alphabetical place in the Encyclopædia, and other impediments having delayed its appearance till now.

The author would be unjust to the editors of the Encyclopædia Britannica did he not acknowledge the benefit this article has derived from their supervision. The multifarious duties of his profession, and prolonged absence from home and on the Continent, have in a great measure precluded his own supervision of the press. To them belong at once the merit and the responsibilities of the active editorship of these articles.

The application of the steam-engine to locomotive purposes has already been treated in the article "Railways" in the preceding volume of the Encyclopædia.

THE STEAM-ENGINE.

It is a singular peculiarity in the history of the steam-engine, that, ever since the period which exhibits the earliest traces of its origin, it has continued slowly and gradually to advance towards maturity, though not yet, perhaps, at ultimate perfection. Our knowledge of the properties and powers of steam, and its agency by machinery, differs widely from the progression of many other arts and knowledge. In the earlier ages of Egyptian science, it appears to have played its part in adding to the imposing effect of those stupendous monuments of absolute power which the storms of many ages have failed to obliterate. In the more refined days of Greece, steam appears to have ministered to the elegance of Attic luxury and the delusions of idolatry; and to have become extensively known until the destruction of the Alexandrian schools dispersed those seeds of science which the flames of its library have spared to Western Europe; and there, imbedded in the ruins of learning during the dark ages they lay preserved, but fruitless, among the other relics of the middle ages; and when at length the light of knowledge again dawned on Europe, the science of the Greek philosophers was exhumed from the rubbish, and became widely diffused by the agency of the press. In this manner the ancient work of Hero on *Pneumatics and Steam Machinery* reappeared as one of the finest and earliest specimens of the art of printing. Since that time, the science of steam, and the art of constructing the steam-engine, have made slow and regular progress, until this useful work of many hands has attained a prominent importance in the interests of mankind, and may perhaps be an element in the future destinies of the world. In this remarkable course, centuries have added their contributions to the elucidation of its principles and the perfection of its mechanism; but no great revolution has ever thrown back this important machine, so as to give occasion for reproducing it.

The progress of the steam-engine has kept pace with the progress of the human mind in physical truth. The same phases which have been severally presented, at widely separated epochs, by successive inventors, are the very phases of gradually growing knowledge by which the mind does most naturally and profitably proceed. Of so large a subject, one part only can be studied at a time. We shall therefore divide this treatise into two parts: the first containing a description of the steam-engine, and the elucidation of its principles, in historical order; the second forming a description of the functions and parts of the modern steam-engine.

PART I.—HISTORICAL DESCRIPTION OF THE STEAM-ENGINE. 1. THE ERA OF THE ANCIENTS. 2. THE ERA OF WORCESTER. 3. THE ERA OF WATT.

1. *The Era of the Ancients.*

The knowledge which some of the ancients possessed of the constitution of steam is remarkably in accordance with some recent conclusions on this species of matter. Steam is now known to be only one of the common airs or gases which, under one state of temperature and of pressure, assume a liquid form, and under another become solid ice.

Matter is known to exist in four conditions—solid, liquid, aerial, and etherial. Earth and stone are exemplars of solid matter; water and mercury of liquid matter; the atmosphere, and smoke, and steam, of aerial substances; heat, light, and electricity, of etherial matter. It is further probable that no kind of matter exclusively possesses one of these conditions as its distinguishing property, but that all may, in certain circumstances, assume different conditions. Stones have been melted by the action of heat under pressure; and iron or lead, though usually solid, may be presented in the liquid form; and the earths have likewise assumed the form of liquids when the contrivance of the chemist has succeeded in placing them in appropriate circumstances. Neither is water essentially a liquid, for, when frozen, it becomes a solid, with which we may construct houses, bridges, utensils, and even floating structures; and on the other hand, it is sometimes reduced into the vaporous or aerial form, as when water in a vessel, acted on by heat, is wholly dissipated and dispersed in an invisible form in air.

It is also to be observed, that the condition of a body may be changed by the agency of heat. Solid ice, solid mercury, or solid lead, by the addition of heat, are converted into liquids or are melted; and then form liquid ice, (called water,) liquid mercury, (called quicksilver,) and liquid lead, (which has no separate name.) If to the liquid thus produced from the solid we add a certain other portion of heat, which will separate its particles still further from each other, the matter thus diffused through more extended space becomes reduced to the aerial condition of steam, of mercurial or lithargical gas, or transparent vapour. But still the matter has undergone no constitutional change. It is only necessary to remove the heat, and the particles will again come together and resume their primitive form. By cooling down the aerial gas into which the matters had been dissipated, or even by compressing them, so as to contract them into their original bulk and bring them together into their original proximity, the particles will again resume their pristine form, the vapours will respectively appear as drops of liquid water, mercury, or lead, and those liquids being farther cooled will congeal into the original solid masses. Some of the most refractory gases have actually been found to obey this law, and probably every substance in nature may be susceptible of each of these forms.

The following passages, taken from the *Timæus* of PLATO, present a remarkable accordance with these enlarged views of the constitution of steam and other gases: —"Let us therefore speculate concerning the nature and properties of fire and water, air and earth. This is the more arduous, because it is necessary to call into question, concerning each and all of them, whether they should be denominated liquid rather than etherial, or aerial rather than solid; or why any thing should have one of these appellations rather than all. For, in the first place, that which we now call 'water,' being congealed, becomes (hard) as a stone or earth, but being melted and diffused becomes gas or air, and this inflamed becomes fire, and fire extinct becomes again congregated into air, and air collected and condensed forms mist and cloud, and these again, more compressed, form water, and from the water earth and stone are reproduced. And thus they, in an endless circuit, produce each other. Since, then, these now appear to be the same, who will assert that one of them is of the one kind rather than the other? It is most safe, therefore, to speak thus: that the thing we see is not absolute liquid, but something in the liquid state. That air is not necessarily a gas, but something in the gaseous state; not as being a particular thing of this or that specific nature, but that it is in such and such a condition.

"Let us then distribute the four modifications of matter into fire, earth, water, and air; and to earth let us assign an entical form, for it is the most immovable of all these kinds—to water that which is less movable than the other three—to fire the most easily movable form—and to air that which is intermediate."

It appears to us highly probable that the ancients knew more of the phenomena of steam than has been generally admitted. One evident cause of this mistake is, that no specific term equivalent to the word steam was generally used by them; and water, when heated, was said to be converted into an air. It is now almost perfectly established that steam is an air, (or gas,) invisible and perfectly transparent, differing in none of its mechanical properties from common air or gas, and in no respect dissimilar to carbonic and other gases or airs which, at certain temperatures and pressures, do, like steam, leave the elastic aerial form and become liquid or solid. Many of the phenomena, therefore, for which the ancients use the word air, are effects of steam, or of steam mixed with air; and although they have not always carefully distinguished these separate effects, yet they have frequently made judicious use of them. While, therefore, it would be wrong to draw any parallel between the want of individualization manifested in their writings, and the high generalization of modern science, it would be equally wide of truth to deprive them, as has sometimes been attempted, of the merit of having discovered and used some of the properties of water in the aerial state, simply because they supposed it rarefied into an air, and confounded its phenomena with those of other gases, which, mixing with it, also contributed to the effect—as when we find that air rarefied by heat, and water rarefied into air, are mentioned.

HERO OF ALEXANDRIA, in his *Pneumatics*, has collected the science and inventions of the ancients, along with some of his own, into a systematic treatise, written in Greek, more than 120 years before the Christian era, some passages of which are identical with portions of modern treatises on pneumatics; and many portions of his apparatus may be found transformed into modern experimental models in cabinets of the physical schools. Thus in the introductory portion of his work, we have such statements as these:—*Water is transformed into air by the action of fire. For the vapours of boiling caldrons are nothing else than attenuated moisture expanding into air.* Indeed, by the four elements the ancients appear to have meant the same things which we now designate by different terms. We comprehend all the material agents with which we are acquainted under the four great designations, solids, liquids, air, and ether. So exactly had the ancients their πυρ and αηρ, ὑδωρ, and γη, to which they assigned different regions according to their weight; first, the solids or earth, then the liquids above, next the aerial covering, and finally the region of ether extending indefinitely beyond. The moderns have shown that all bodies are probably capable of assuming any of the three states, and becoming solid, liquid, or fluid, according to the circumstances in which they are placed; and we have every reason to believe that Timæus, of whom Plato speaks with so much reverence, entertained the same idea, and believed that even the air might assume the state of a crystalline solid. It is not a little curious to find the late eminent mathematician, M. Poisson, giving it as a result of his calculus, that the air at a great distance from the earth is actually frozen into a crystalline solid by the extreme depression of temperature. He was probably not aware that his notion had been anticipated more than 2000 years. In this same work of Hero, we have descriptions and explanations of apparatus, in which fire acting on moisture and air is made to produce phenomena of motion. He does not arrogate to himself the merit of these inventions, but has given them as principally a collection from the works of others who had long preceded him.

His *Pneumatics* commence with a lucid and excellent dissertation on the properties of air as a medium for the communication of pressure and motion, and especially upon the nature and effects of a vacuum, subjects to be thoroughly understood by all who would master the theory of the steam-engine. It is, indeed, as the means of producing a vacuum, that steam obtains much of its value as a mechanical power. The mode of raising water by a vacuum is thus described by him:—"When they wish to fill with water the round medical glasses which have slender long necks, they suck out the air which is contained in them, and, closing the orifice with the finger, they invert them in the water, and on removing the finger the water is drawn up into the vacuous space, in contradiction to the usual law of fluids." He then proceeds to state that, "in like manner, air may be rarefied by heat even as other substances are; for water is changed by fire into air, the vapours from boiling caldrons being nothing else than expanded water taking the form of air, and that mists and clouds are nothing else than water raised in the air by heat, which are partly afterwards converted into air, while portions again descend in rain." He also attributes the origin of winds to the "expansion and contraction of air and moisture by the alternate heating and cooling produced by the sun's rays;" and illustrates the conversion of liquids into air or gas by the common observation, that, after a lamp has gone out, the vapour continues to rise up by the heat still left in it by the flame. Thus also, says he, a phial being filled with

Fig. 1.

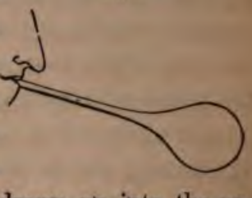


Fig. 2.

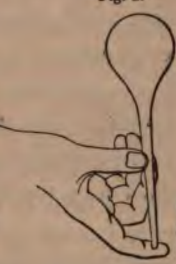
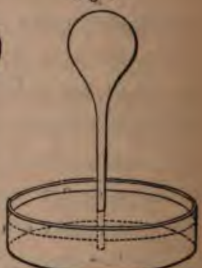
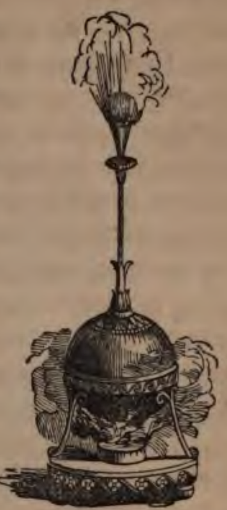


Fig. 3.



heated air and inserted in water, this air contracting will draw up water into the phial. Hence, he argues, that all airs consist of inconceivably small particles of matter, between which there are left wide vacuous spaces, so that, while the matter itself is incompressible, the volume occupied by the aggregate may be increased and diminished, and the air rarefied and condensed either by external force or the action of heat.

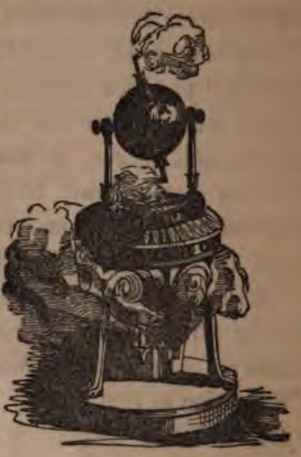
Fig. 4.



The following description of the manner in which the force of steam, issuing from a boiler, may be applied to support a weight, is given in the *Pneumatics*. "A boiler perforated on the top, is placed on the fire. From the perforation there proceeds a tube, on whose extremity is fixed a hollow hemisphere perforated in like manner. If then we place a light ball in the hemispherical cup, it will follow that the vapour rising up from the boiler through the tube will support the sphere, and it will appear to dance."

There is another apparatus in the *Pneumatics* for producing a revolving motion by the action of steam —"by a caldron placed on a fire to give motion to a sphere around its axis. Let a boiler be set on the fire, and nearly filled with water, and let its mouth be closed in by a cover, and let it be pierced with an opening through the bent tube, whose extremity exactly fits into the hollow sphere.

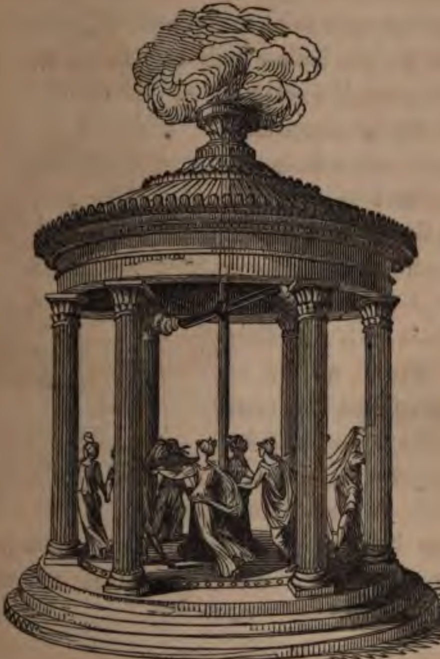
Fig. 5.



But at the opposite extremity of the diameter let there be an iron axis supported from the top of the cover; and let the sphere have two bent pipes at the ends of a diameter perforated along with it, and bent round in opposite directions; and let the bendings make right angles and be in the plane perpendicular to the axis. Then it will follow that, on the boiler being heated, the vapour rushing through the tubes into the sphere will rush out through the reversed pipes of the ball, and whirl it on its axis.

The same apparatus, on similar principles, is next applied by Hero to the construction of a machine still more curious. The agent mentioned in this case is rarefied air, although the action is of precisely the same nature. Here the science of the philosopher appears to have been degraded to assist the priesthood in deceiving the populace by the resemblance of miraculous interference. "A fire having been kindled upon an altar, living figures will appear to lead a choral dance, even although the altar itself be of transparent glass or horn. Through the epipyrus a pipe is to be let down to the base of the altar, where it is to revolve on an iron pin, the other end being passed through a tubular fitting attached to the epipyrus. And this pipe is to have other little cross pipes attached to it, and perforated, so as to communicate with it, (which are to radiate opposite to one another around it,) and turned alternately

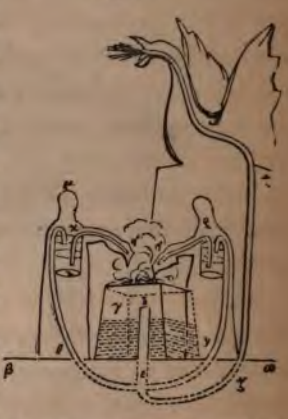
Fig. 6.



in opposite directions in the ends. There shall likewise be a drum attached to it, upon which the figures of the dance are to be set. Then, by the action of the kindled fire, the air, being warmed, will proceed into the pipe, and from it being driven out through the bent tubes in the base of the altar, will turn round the pipe and its drum."

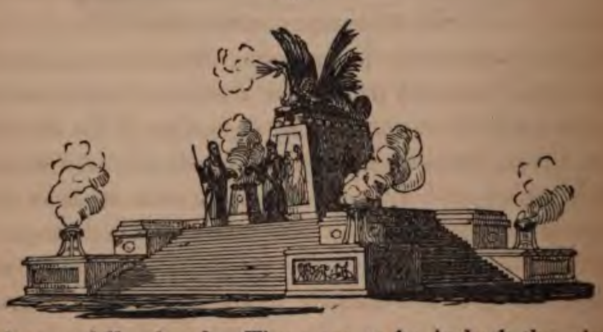
The following is probably the most excellent of all Hero's apparatus, inasmuch as in it steam is employed for elevating a fluid, and transferring it from one place to another. The design of the apparatus was still, unhappily, to aid superstitious worship. "The fire of an altar having been lighted, two figures of living things are to assist at the sacrifices, and the figure of a dragon is to sibyllate," (or give forth sounds to be interpreted as oracles.)

Fig. 7.



There is to be a hollow basis or pedestal $\alpha\ \beta$, (fig. 7,) upon which is set the altar γ, having a tube $\delta\ \varepsilon$ descending to the middle of the basis, and there separated into three branches; the tube $\varepsilon\ \zeta$ passing to the mouth of the dragon, the tube $\varepsilon\ \theta\ \kappa$ being carried to the vessel $\kappa\ \lambda$ containing wine, and placed at the top of the figure μ, and accurately joined into its cover; and into the third tube $\varepsilon\ \nu\ \varrho$, which, in like manner, ascends into ϱ, another vase holding wine, and is also accurately united to the top of the vase. Both ends of the two vases are to be carefully closed. There are to be in both the wine vessels bent syphons $\varrho\ \sigma\ \tau\ \kappa$, of which the one extremity is

Fig. 8.



in the wine, and the other extremities, proceeding by an opening rendered perfectly close through the covers of the vases, are conducted to the hands of the figures officiating at the sacrifice. When, therefore, you are about to sacrifice, you must pour into the tubes a few drops lest they should be injured by heat, and attend to every joint lest it leak; and so the heat of the fire, mingling with the water, will pass in an aerial state through these tubes to the vases, and, pressing on the wine, make it pass through the bent syphons, until, as it flows from the hands of the living creatures, they will appear to sacrifice as the altar continues to burn, and the other tube being carried to the mouth of the dragon, will make it give forth sibylline sounds."

There is considerable reason to suppose that, to their knowledge of the elements of machinery, the Egyptians added some acquaintance with the power of steam, applied, however, only to the degraded service of superstition. The statue of Memnon is said to have emitted sounds which Pausanias compares to those produced by the snapping of the strings of a harp. Strabo expressly states that he heard them; and Philostratus states, that when the sun shone strongly on the statue, sounds issued from its mouth similar to those of a stringed instrument. Hero of Alexandria in his *Pneumatics*, Salomon de Caus in his *Raisons des Forces Mouvantes*, Athanasius Kircher in his *Œdipus Egyptiacus*, and Cribellus in his *Machinosa Miracula Memnonis*, have all explained in different ways the mechanical arrangements by which effects of this kind might have been produced from the steam raised by the heat of the sun in close vessels concealed in the statue, and communicating with organ pipes of different kinds.

The Romans appear to have done little for the mechanical arts, and nothing for the improvement of steam apparatus. It was not until the dawn of knowledge succeeded the darkness of the middle ages, that the light reflected from the works of Hero, and the older mechanicians, rekindled the flame of mechanical invention. The works of Archimedes and of Hero were read with great avidity, and formed some of the most popular productions of the young art of printing. The flame seems first to have been lighted in Italy, for we have editions and translations of Hero's *Pneumatics* rapidly succeeding each other; the Bologna edition of 1547, translated by Giovanni Baptista Aleotti, was reprinted at Ferrara in 1589; Commandine's translation was published in 1575, Alessandro Giorgi's in 1592. There were other editions of less note; and thus in a single century eight or nine editions were issued. It was not to be expected that the seeds of mechanical knowledge, so widely sown, should not fall on some rich soil, where they should bring forth fruit with increase.

Giambattista della Porta was one of the ablest and most ingenious expositors of the principles of pneumatics. A work which he published on this subject contains the following passage:—" Make a box of glass or tin, having at the bottom an aperture, through which is inserted the neck of a distilling flask, containing one or two ounces of water, and let its neck be cemented into the bottom of the box, that there be no escape. About the bottom of the box let there rise up a pipe at such a distance from the bottom as to permit the water to escape, which pipe passing through the cover shall rise a little way above its surface. The box is to be filled with water by an aperture which is to be well closed, so that no air may pass. Finally, place the said bottle on the fire, and heating it slowly, the water being gradually dissolved into air, will press upon the water in the case, and pressing with great force upon the water which issues through the pipe (the steam,) will not make its escape. And if we continue the application of heat, the whole of the water (in the flask) will be at last exhausted; and while the water is evaporating, the air (vapour or gas) will constantly press on the water in the vessel, and the water will continually issue out. The exhalation being finished, if you will measure how much water is out of the box; that which is in the place of the water gone out, will give the measure of the remaining water. Thus you find, from the quantity of water used, how much water was dissolved into so much air. And, in like manner, also, you can measure into how much of more rarefied air, air of the ordinary density can be dissolved."*

Here we perceive that the knowledge of the conversion of water into air or gas, taught by Hero's *Pneumatics*, was extending itself in that country, and leading to further contrivances; and we have also a beautiful and simple experiment, designed for determining the philosophical question, which formed an interesting subject of research at a very recent period of physical enquiry, "how much aqueous vapour is formed by a given quantity of water?" The method is not perfect, for a considerable part of the vapour would be reconverted into water in the progress of the experiment; yet it shows an acquaintance with the fact, that water heated by fire is converted into aqueous air with sufficient force to raise water above its level, and form a running stream, although, in this case, of no very considerable height.

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* J. B. Portæ Pneumaticorum libri tres. Neapoli, 1601, 4to.

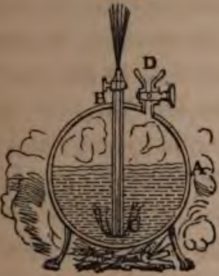
The spirit of invention, aroused by the first translation of Hero's works, did not confine itself to the country in which these works were first disseminated, but spreading gradually northwards, displayed itself in the works of an architect and engineer, Salomon de Caus, who had come to England in 1612, and was employed by the Prince of Wales, afterwards Charles I., to design grottoes, fountains, and other hydraulic ornaments, for the embellishment of the prince's palace at Richmond, and for the gratification of his "gentille curiosité." These, with other machines, were published by him in a work entitled "*Les Raisons des Forces Mouvantes*, avec diverses machines tant utiles que plaisantes; auxquelles sont adjointes plusieurs desseins de grottes et fontaines, augmentées de plusieurs figures." Frankfort, 1615, fol.

The work of de Caus is prefaced by an exposition of the principles of hydrostatics and pneumatics, evidently derived from the writings of Archimedes and of Hero. Among other things, he states that the violence with which water is dissolved into air by means of fire is very great, and that a ball of copper containing water, if placed on a fire, would certainly burst. "La violence est grande quand l'eau s'exhale en air par le moyen du feu . . . il est certain que si l'on met la dite balle sur un grand feu, en sorte qu'elle devienne fort chaude, il se fera une compression si violente que la balle crevera en pièces."

He afterwards shows how a jet of water may be made to rise above its level, and play in the air by means of fire. A copper ball A, (fig. 9,) has an orifice D, at which water is poured in, and it is then closed with a stop-cock.

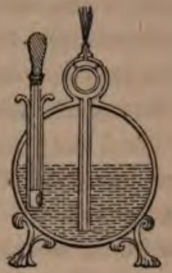
Another tube, B C, is closely fitted to the same ball, but passes down near to the bottom, where it is open in the water; the pipe terminates above in an orifice for a small jet of water, which is regulated by a stop-cock. In fact, the apparatus is precisely that which Hero uses for raising a jet of water, but without the aid of heat, when he forces air above the water, till it raises a jet of water by its pressure, (as exhibited in fig. 10.) Of course, the heat produces the same elastic force in De Caus's machine as the compression of air does in Hero's.

Fig. 9.



De Caus's Diagram.

Fig. 10.



Hero's Diagram.

There seems no reason to doubt that Salomon de Caus was a Frenchman, and he is said to have been a native of Normandy.* In dedicating his work to the French monarch, he describes himself as one of his subjects. After leaving England he settled in Germany, where the Elector Palatine intrusted him with the superintendence of his buildings and gardens. He finally returned to France, and died there about the year 1630. He has sometimes been confounded with Isaac de Caus, a native of Dieppe, and a descendant of the same family, who published

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* Biographie Universelle, tom. vii. p. 433.

"*Nouvelle Invention* de lever l'Eau plus haut que sa source, avec quelques machines mouvantes par le moyen de l'eau, et un discours de la conduit d'icele." Lond. 1644, fol. This work contains many machines identical with those described by Salomon de Caus; and the similarity of subject, treatment, and titles of the two, has led those into much confusion who may not have examined both. Even the pains-taking and industrious Stuart seems to have been deceived, and calls Isaac's book a later edition of Salomon's.

The direct emission of steam from an orifice of the boiler, which had been used by Hero to sustain the ball in the air, was applied by Branca, an Italian architect and engineer, to impress a revolving motion on the vanes of a wheel like a common mill-wheel, and this communicating with a series of toothed wheels gave motion to a series of pestles in mortars. This and many other machines which he states he collected from the inventions of others, were published in a quarto volume entitled *Le Machine.* "Volume nuovo et di molto artificio da fare effetti maravigliosi si tanto spiritali quanto di animale operatione: arrichito di bellissime figure conle dichiarationi a ciascuna di esse in lingua volgare et Latina, del Sig. Giovanni Branca, cittadino Romano, ingegniero et architetto della sta. casa di Loretto. In Roma, M.DC.XXIX." This period appears to have teemed with curiosities of mechanical invention; and the learned virtuoso who would take the trouble of ransacking the mechanical productions of the sixteenth and seventeenth centuries, would be able to collect materials for an interesting, curious, and amusing volume. Perpetual motions were very common; wings for enabling men to fly in the air, mechanical chariots for a similar purpose, conveyances to the moon, and engines for making continual and cheap music by mills or by fire, for rocking of cradles and turning of spits, were favourite subjects of design; and many of these curious contrivances, without serving any definite purpose, form elegant and curious pieces of apparatus. We are now passing from the era of the curiosities of mechanical contrivance, into that period when the same principles that actuated the toys of Hero and the automata of Kircher were to be applied to move most useful machines for the advancement of the human race.

2. *The Era of Worcester.*

Edward Somerset, Earl of Glamorgan and Marquis of Worcester, invented and constructed the first steam-engine. His title to this honour has been the subject of dispute, some historians attributing to him a greater share of merit than there was sufficient evidence to warrant, while others deprive him of even that honour to which he possesses an indefeisible claim. His life is one of the most romantic chapters of English history. Enterprising, generous, disinterested, and confiding, he was first beloved and then betrayed by his king, loaded with honours and reduced to poverty; at one time exercising almost without control the functions of the sovereign, conferring dignities from the rank of marquis down to baronet, and at another thrown into prison, and begging from a creditor the paltry loan of five pounds. Possessing inventive genius of the highest order, he was considered a mad enthusiast because his speculations were far in advance of the age in which he lived, and he has been set down a quack and impostor by men incapable of comprehending the nature or appreciating the value of his creations. The slow march of knowledge and of time has at last revealed the worth, and established the character, of an illustrious and unfortunate man of genius, who only lived to complete his design and carry it happily into effect.

That the Marquis of Worcester was acquainted with the nature and force of steam, no one has ever disputed; but it has been matter of serious doubt whether the machine which he has described had ever any real existence. Hitherto we have had nothing more than circumstantial presumptive evidence of the actual construction of the marquis's steam-engine. It is only a few years since the industry of the indefatigable antiquary Robert Stuart has presented us with an historical document of undoubted authenticity, affording undeniable proof of the existence and efficiency of one of the engines of the Marquis of Worcester, of more than two horse-power, employed for raising water on the Vauxhall side of the river Thames. As the marquis's title to the invention had not been established in any of the numerous treatises on the steam-engine that had appeared previously to the former edition of this volume, and as the proof we are now able to adduce must for ever set at rest the querulous cavillings of those otherwise respectable writers who have attempted to controvert the great truth that the steam-engine is a machine wholly of British invention, we shall give a short account of what the marquis undoubtedly accomplished.

We are principally indebted for our acquaintance with the mechanical inventions of the Marquis of Worcester to a very small work in which he published a list of one hundred of his mechanical inventions, under the title of "A Century of the Names and Scantlings of such Inventions as at present I can call to mind to have tried and perfected, which (my former notes being lost), I have, at the instance of a powerful friend, endeavoured now, in the year 1655, to set these down in such a way as may sufficiently instruct me to put any of them into practice." Lond. 1663, 12mo. Of this remarkable work there are several other editions. Before noticing the passages which have immediate reference to the high-pressure steam-engine which he had invented and made, it may be proper to premise, for the purpose of preventing the supposition from being entertained that it was impossible to get devices of so complex a nature carried into effect at a period when the mechanical arts of construction had made so little progress, that he had constantly employed during thirty-five years, one of the most eminent artificers of the time, named Caspar Kaltoff, and that he had provided him with suitable work-shops, tools, and machinery at an expense of more than ten thousand pounds. It thus appears that the marquis was no mere schemer, but that he submitted his devices to the test of experiment; and it is merely not passing the bounds of credibility to suppose, that, with fertile resources, an active and inventive mind, the best tools, an "unparalleled" artificer, and the expenditure of great sums of money, he had in thirty-five years constructed machines of such perfection as no other artist of his age had accomplished, and few of the hangers-on of a royal court could understand or appreciate. No one who is acquainted with the modern high-pressure steam-engine can fail to recognise it in the following specification, which, be it observed, was given by the marquis rather for exciting curiosity than gratifying it—for stating the capabilities of his engine than for explaining its principle, which he wished to keep secret till he had obtained a patent.

"Invention 68.—An admirable and *most forcible way to drive up water by fire*; not by drawing or sucking it upwards, for that must be, as the philosopher calleth it, 'infra sphæram activitatis,' which is but at such a distance, *but this way hath no bounder, if the vessels be strong enough; for I have taken a piece of a whole cannon*, whereof the end was burst, and filled it three-quarters full, stopping and filling up the broken end, as also the touch-hole, *and making a constant fire under it; within twenty-four hours it burst and made a great crack:* so that, having found a way to make my vessels so that they are strengthened by the force within them, and the one to fill after the other, I have seen the water run like a *constant fountain forty feet high.* One vessel of water rarefied by fire driveth up forty of cold water; and a man that attends the work is but to turn two cocks, that one vessel of water being consumed, another begins to force and refill with cold water, and so successively."

The internal evidence of the truth of this description is too strong to be resisted. We cannot say what ideas it may have suggested to such a man as Lord Orford,* who was probably as ignorant of mechanical principles as he was devoid of candour and charity to a man of principles and religion different from his own; but to any one conversant with the mechanical contrivances and treatises even of that time, it was scarcely possible to read the sentence without forming a distinct conception of a similar apparatus to that here described by the marquis. We shall see that the description was so perfect as to enable a subsequent mechanician to reconstruct the machine of the marquis, with some additions, and produce an effective machine for draining mines. We see, too, how philosophical was the process by which he advanced to the construction of his machine. He made experiments of a conclusive nature on the boundless force of steam. He found that the only impediment to its use was the want of sufficiently strong boilers; and his having found a way to make his vessels so as to be strengthened by the force within them, merely shows that he overcame the difficulty of making steam-tight joints by using internal flanges, which should become tightened by the pressure of steam within them. There is also internal evidence of the genuineness of his description of the quantity of water converted into steam for the effect of raising the water,—" one vessel rarefied by fire driveth up forty of cold water," is a measure of the power of steam far within the compass of its capability. Even under most unfavourable circumstances, an unprincipled exaggerator would not have contented himself with this moderate statement of its actual power.

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* It cannot be denied that the marquis has given occasion for animadversion. His design of having his machine buried with him, was just like a child wishing to sleep with its toy. But he appears to have judged very favourably of the credulity of his readers; as, for instance, when he expected them to believe that he had "invented and perfected" a perpetual motion. His account of this, especially in some copies of his work, has no parallel for inconsistency and absurdity. Yet he says he exhibited it in operation before the king, the most of his court, and other great ones. Why did it not supersede the steam-engine, and every other moving power?

But we have not yet concluded the marquis's description of the nature of his stupendous prime-mover; for his mind, in dwelling upon its principles, applications, and powers, gradually became assured that his engine was to become the most important and powerful agent in the whole world, and appears, even at that remote era, to have obtained a glimpse of the multifarious avocations and powers of the modern steam-engine. He proceeds to describe "an engine so contrived, that working the *primum mobile* forward and backward, upward or downward, circularly or cornerwise, to and fro, straight upright or downright, yet the intended operation continueth and advanceth, none of the motions above mentioned hindering, much less stopping the other, but unanimously and with harmony agreeing, they all augment and contribute strength unto the intended work and operation; and therefore I call this a semi-omnipotent engine, and do intend that a model thereof be buried with me."

"How to make one pound weight to raise an hundred as high as one pound falleth, and yet the hundred pound descending doth what nothing less than one hundred pounds can effect."

"Upon so potent a help as these two last-mentioned inventions, a water work is, by many years' experience and labour, so advantageously by me contrived, that a child's force bringeth up, an hundred foot high, an incredible quantity of water, even two foot diameter, so naturally, that the work will not be heard into the next room; and with so great ease and geometrical symmetry, though it work day and night from one end of the year to the other, it will not require forty shillings' reparation to the whole engine, nor hinder one day's work; and I may boldly call it the most stupendous work in the whole world; and not only with little charge to drain all sorts of mines, and furnish cities with water, though never so high seated, as well as to keep them sweet, running through several streets, and so performing the work of scavengers, as well as furnishing the inhabitants with sufficient water for their private occasions, but likewise supply rivers with sufficient to maintaine and make them portable from towne to towne, and for the bettering of lands all the way it runs, with many more advantageous and yet greater effects of profit, admiration, and consequence; so that, deservedly, I deem this invention to crown my labours, to reward my expenses, and make my thoughts acquiesce in the way of further inventions."

To any one who is familiar with the advantages which [illegible] as London derive at this moment from having [illegible] raised up by fire and distributed through the highest houses for private use; who has witnessed the incredible quantity of water brought up by a Cornwall, or Newcastle, or Staffordshire steam-engine from enormous depths, by the descent of a piston not the thousandth part of the weight which it raises through an equal height; who has observed the elastic force of steam in a cylinder performing in any and every position its multifarious duties and that a child's force is sufficient to control and guide that stupendous power, it must be most obvious that we have only carried to perfection that engine which the Marquis of Worcester first conceived and made.

Some points in the statement of the marquis, which had not formerly been noticed, have received considerable elucidation, by a manuscript account of his inventions, discovered a few years ago by Mr Robert Stuart, and by another document, of no small importance in this question, which was brought to light by the zeal and industry of the same writer, viz. a Diary of Cosmo de' Medici, Grand Duke of Tuscany, who visited England about the year 1656, in which he gives an account of the engine invented by the Marquis of Worcester, which he had seen in operation at Vauxhall.

The Condensing Steam-Engine of Captain Savery.

About thirty years after the marquis's death, which happened in 1667, the condensing steam-engine was invented by an Englishman, Captain Thomas Savery, and was by him introduced for draining mines, raising water for buildings and gardens, and generating a revolving mechanical power. He exhibited a model of it to the Royal Society of London in 1699. (*Phil. Trans.* vol. xxi. p. 228.) We have seen that the marquis's model appears to have been placed on or below the level of the water to be raised, and that his vessels being filled, their contents were raised by the elastic force only of the steam. Mr Savery, on the other hand, erected his engine at a height of nearly thirty feet above the level of the water. A large close vessel was filled with steam; this steam was reconverted, by cooling the outside of the vessel, into water, leaving the large space it had formerly occupied vacuous; into this vacuum water was raised, as into the vacuum of a common sucking pump, by atmospheric pressure, and so within the limit of atmospheric pressure, raised twenty-eight or thirty feet. After this was accomplished, the water was further raised by the elastic force of the steam, just as in the engine of the Marquis of Worcester. But the improvement was great. The same force of steam, strength of vessels, and consumption of fuel which were sufficient on the marquis's plan to raise water thirty feet, would be capable first of drawing up the water thirty feet, and then thirty more; or doing double the work, or sixty feet of height on Savery's plan. This was certainly a notable improvement.

There has been considerable discussion among the historians of mechanics regarding the merits of Worcester and of Savery. Those who have thought proper to praise the inventive talent of the one, have thought it essential to their purpose to depreciate the merit of the other. We think their claims rest on independent grounds. The Marquis of Worcester expressly disclaims the use of a vacuum, which, on the other hand, is the distinguishing feature of Captain Savery's, when he says, "not by drawing or sucking it upward, for that must be as the philosopher calleth it, *infra sphæram activitatis*, which is but at such a distance; but this way (by high pressure) hath no bounder, if the vessels be strong enough." It appears, therefore, to us, that the inventions were quite independent and different; and we have no hesitation in admitting it as exceedingly probable, that when Captain Savery added the principle of high pressure to his own principle of a vacuum from condensation, he was not unacquainted with the marquis's works, and even with his engine for raising water by fire, for which he had obtained a patent, and which he had erected at Vauxhall. While we have thus expressed our own opinion of the independence of their claims, we must not omit the opinions of others who lived nearer to the epoch of these rival candidates.

Dr Desaguliers, an eminent mechanist, and philosopher of considerable reputation, has given, in his *Experimental Philosophy*, vol. ii., an account of the "fire-engine," and after adverting to the claims of the Marquis of Worcester, makes the following statement in regard to Savery:—"Captain Savery having read the Marquis of Worcester's book, was the first who put in practice the raising water by fire, which he proposed for the draining of mines. His engine is described in Harris's *Lexicon*, (see the word ENGINE,) which, being compared with the Marquis of Worcester's description, will easily appear to have been taken from him; though Captain Savery denied it, and the better to conceal the matter, bought up all the Marquis of Worcester's books that he could procure in Paternoster Row and elsewhere, and burn'd 'em in the presence of the gentleman, his friend, who told me this. He said that he found out the power of steam by chance, and invented the following story to persuade people to believe it, viz., that having drunk a flask of Florence at a tavern, and thrown the empty flask upon the fire, he called for a basin of water to wash his hands; and perceiving that the little wine left in the flask had filled up the flask with steam, he took the flask by the neck and plunged the mouth of it under the surface of the water in the basin, and the water of the basin was immediately driven up into the flask by the pressure of the air. Now, he never made such an experiment, then, nor designedly afterwards, which I thus prove: I made the experiment purposely with about half a glass of wine left in a flask, which I laid upon the fire till it boiled into steam; then putting on a thick glove to keep the neck of the flask from burning me, I plunged the mouth of the flask under the water that filled a basin; but the pressure of the atmosphere was so strong, that it beat the flask out of my hand with violence, and threw it up to the ceiling. As this must also have happened to Captain Savery, if ever he had

Fig. 11.

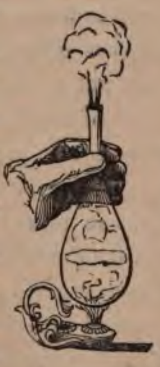
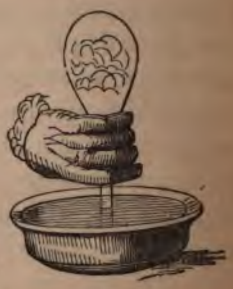


Fig. 12.



made the experiment, he would not have failed to have told such a remarkable incident, which would have embellished his story."

We have performed the doctor's experiment frequently, with various results. If the mouth of the flask happens to be large and its neck short, the water very cold, and the flask very perfectly filled with steam, the effect is exactly what Desaguliers describes; for the vacuum being suddenly and completely formed, the flask is first pressed down towards the basin, which the hand resists by sustaining the flask in the opposite direction, and just then the water rushes with great velocity up into the vacuum, and striking on the bottom of the flask, now turned upwards, is apt to knock it suddenly out of the hand, especially when held merely by a soft glove. But if, on the other hand, the flask has a narrow mouth and long neck, and if, when inverted, its neck be allowed to rest on the bottom of the vessel, and if the water in the basin be not very cold, it will rise slowly and gently, and the flask will be completely filled.

The doctor's inference is not, therefore, perfectly just to Savery, who, although he had read Worcester's book, would not find in it any such principle, but an express exception from it, as we have already stated.

Stephen Switzer, author of a *System of Hydrostatics and Hydraulics*, published at London in 1729, takes a different view of the matter. In the chapter "On the Engine for raising Water by Fire," he gives the following account of it:—"Amongst the several engines which have been contrived for the raising of water for the supply of houses and gardens, none has been more justly surprising than that for the raising of water by fire; the particular contrivance and sole invention of a gentleman with whom I had the honour, long since, to be well acquainted—I mean the ingenious Captain Savery, some time since deceased, but then a most noted engineer, and one of the Commissioners of the sick and wounded.*

"This gentleman's thoughts (as appears by a preface of his to a little book entitled *The Miners' Friend*) were always employed in hydrostatics or hydraulics, or in the improvement of water works; and the first hint from which it is said he took his engine, was from a tobacco-pipe, which he immersed to wash or cool it, as is sometimes done. He discovered that the water was made to spring through the tube of the pipe in a wonderful and surprising manner; though others say that the learned Marquis of Worcester, in his *Century of Inventions*, (which book I have not seen,) gave the first hint for this raising water by fire.

"It was a considerable time before this curious person, who has been so great an honour to his country, could bring this his design to perfection, on account of the awkwardness of the workmen who were necessarily to be employed in the affair; but at last he conquered all difficulties, and procured a recommendation of it from the Royal Society, (*Phil. Trans.*, 252,) and soon after a patent from the Crown, and I have heard him say myself, that the very first time he play'd, it was in a potter's house at Lambeth, where, though it was a small engine, yet it (the water) forced its way through the roof and struck up the tiles in a manner that surprised all the spectators."

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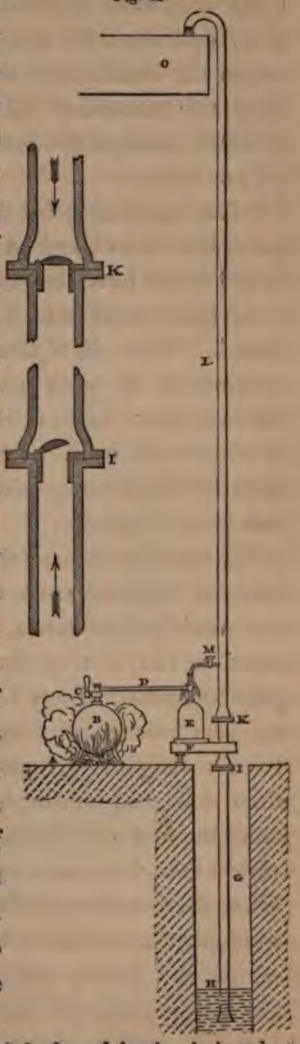
* This renders it more probable that Savery had been styled Captain from his having held some appointment in the public service, than that (as some have conjectured) he had been the superintendent of a mine, and so called, as is usual in Cornwall, a Captain.

"About the year 1699, he wrote a small pamphlet or treatise concerning this engine which I have just now mentioned, wherein he has exhibited a draught of it; but as that consisted of a double receiver, and a great many particulars not so easy for a learner at first sight to understand, I have, first of all, inserted that draught of it, and the account thereof, which Mr Bradley, in his *Gardening*, has given us of that at Cambden House, it being an engine of Mr Savery's own invention.

"A the fire; B the boiler, a copper vessel of a spherical figure in which the water is boiled and evaporated into steam, which passes through the regulator C, which opens to let it into D the steam-pipe, of copper, through which it descends into E the receiver, which is a vessel of copper also, that at first setting to work is full of air, which the steam discharges through F the engine tree, and up the clack valve at K, and so the air ascends in L the force pipe.

Fig. 13.

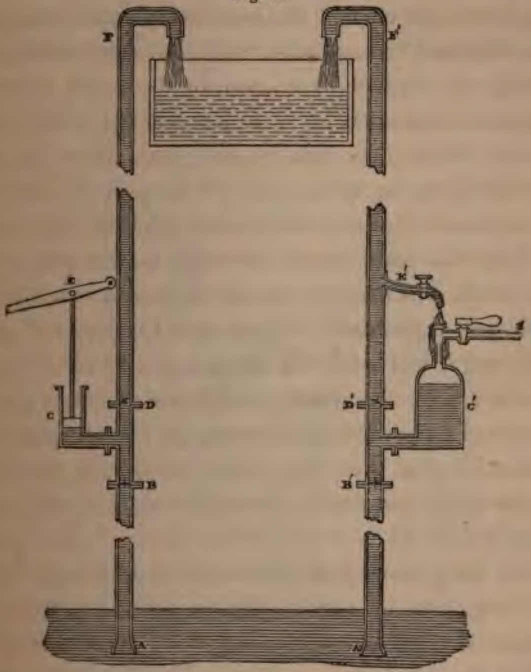


"After E is void of air, which is found by its being hot (with steam) all over, then stop the steam at C, and throw a little cold water on the outside of the hot receiver E, so as to cool down the steam in the inside, and so make it resume the condition of water, leaving E a vacuum, into which the pressure of the atmosphere will raise a column of water through the sucking pipe G from H, the pond, well, or river.

"This being done, and the receiver now being filled with water, first turn C, and let the steam pass into the receiver E, and it will force the water therein through F by K up to L, which water cannot descend because of the clack valve I. When E is thus emptied, which may be easily perceived by its being hot, as before, turn C, and confine your steam in B, then open the cock M, which will let a little cold water on E, and that, by condensing the steam in E, will cause the water to ascend immediately from H and replenish E. Then turn C to let the steam into E, and it will force the water out of it up L, into a cistern at O, placed at the top to receive it. Then confine your steam at C as before, and turn M for the space of a second or two of time, and E will be refilled, and may again be discharged up L as before; so that this work may be continued as long as you please. The valves placed in the pipes at I and K are shown on a larger scale at the side, and will enable the reader to see how they permit the water to ascend, but prevent its return by the weight of the water pressing down the clack.

It seems to us very probable, from the form of Savery's engine, that it was taken directly from that of a common drawing and forcing pump, with the substitution of the force of steam only for that of the pump piston. In Fig. 14, A B C D E F represent a common forcing pump, as given in the hydraulic works of that epoch. A′ B′ C′ D′ E′ F′ are the parts of one of Savery's steam-pumps. In the case of the common pump, the solid piston or plug at C, exactly fitted to the cylindrical chamber at C, is forced down by the lever E upon the water in the chamber C, which is pressed out through the pipe at the bottom, and being prevented from passing down to A by its closing the valve B, is forced up through the open valve D, and raised towards the reservoir F. When the chamber C is thus emptied, the piston is again raised, and being so tight, that no air can enter, the water is carried

Fig. 14.



up through the valve B, which only opens upwards, and thus the vacuum at C is filled from below, by atmospheric pressure, with water, which is again to be forced back by the descent of the piston; but as the valve B closes by the pressure above it, and the valve D opens upwards, the water is forced upwards and delivered at F. Now instead of the solid piston of the pump, we have only to substitute the agency of steam, and we have Savery's machine. The close chamber C′ being conceived full of water, steam from the boiler is admited by S′, and, by its elastic force, depresses the water at C′ so as to force it out of the receiver; and finding no exit by the closed valve B′, it is forced through the rising valve D′ towards the reservoir F′; in these circumstances the little jet brought from the pipe E′ is allowed to throw cold water for a second or two on the close chamber C, now filled with steam, which is immediately condensed into the small quantity of water from which it was originally formed, and leaves a vacuum into which, as in the former case, water is carried up by the force of the atmosphere, so as again to replenish the chamber C′, as at first, with water, which is in its turn to be acted on by the steam admitted through S′, and forced up through D′ F′ to be delivered at F′.

The reader who has followed this examination of Savery's engine in its earlier form, is now prepared to understand the more complex but more efficient form in which it was much oftener used. This form was that of the double receiver. The form hitherto examined did not produce a uniform stream, because the receiver, after having emptied its contents, required a considerable interval to fill again.

The following description of the double machine, which rendered the stream nearly constant, is abridged from Savery's treatise, *The Miners' Friend.* London, 1702.

Fig. 15 represents this engine as applied to draw water from deep mines. It is placed under ground, on a platform from twenty to thirty feet above the level of the water. The chimney ascends in the shaft of the mine along with a pipe through which the water is forced to the surface.

A represents the furnaces; B^1 B^2 the two fire-places; C the chimney; D the small boiler; E F the cock and pipe of it; G a small cock to a pipe going within eight inches of its bottom; H a large pipe going the same depth; I a clack in said pipe opening upwards; K a pipe

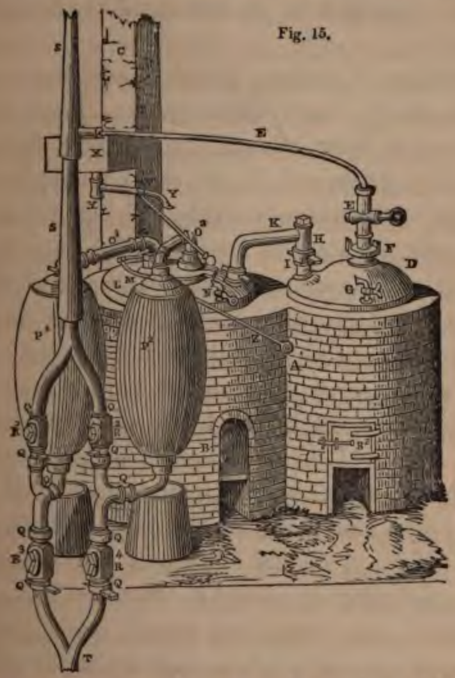


Fig. 15.

going from said clack or valve about an inch into the great boiler; L M the screw with the regulator; N a small cock and pipe going half way down the great boiler; O^1 O^2 steam pipes, one end of each being screwed to the regulator, and the other to the vessels P^1 P^2 called receivers; Q, Q, Q screw joints in the pipes, and at R, R, R, R, Nos. 1, 2, 3, 4, are valves or clacks opening upwards; S is the force pipe; T the sucking pipe, with holes round its bottom in the water; X a cistern, with a buoy-cock coming from its bottom; Z the handle of the regulator.

The manner of working this engine is, first: unscrew G and N, the two small gauge-pipes and cocks of the two boilers, and at their holes fill L, the great boiler, two-thirds full of water, and D, the small boiler, quite full; then screw in the said pipes again, and light the fire at B, No. 1; when the water in L boils, the handle of the regulator, marked Z (near to A) must be thrust to the right as far as it will go, which makes the steam rising from the water in L press through O No. 1, into P No. 1, making a noise as it goes; and when all is gone out, the bottom of the vessel P No. 1 will be very hot. Then pull the handle of the regulator to the left, which will stop O No. 1, and force the steam through O No. 2 into P No. 2, until that vessel has discharged its air through the clack R No. 2 up the force-pipe. In the meantime let some cold water be poured on the vessel P No. 1 from the spout Y, and then by the steam's condensing in that vessel, a vacuum is created, so that the water will necessarily rise by the pressure of the atmosphere up through T, the sucking pipe, lifting up the clack R No. 3, and filling the vessel P No. 1.

The vessel P No. 2 being emptied of its air and filled with steam, pour some cold water upon it too; and then P No. 2 will be filled with water as the other was. But having previously turned the handle of the regulator again to the right, the force of the steam will be upon the surface of the water in P No. 1; and will be still increasing till it overcome the weight of the water ascending in the forcing pipe S, so that the water in P No. 1 will be immediately discharged and forced up to the reservoir. When all the water is forced out, the steam, escaping through R No. 1 will rattle the clack, so as to give notice to pull the handle of the regulator to the left, which at the same time begins to force out the water from P No. 2, without much alteration of the stream. This being done, turn the cock or pipe of the cistern X on P No. 1, so that the cold water may condense the steam in it, and then the vessel P No. 1 will be refilled with water while P No. 2 is emptying. Next turn the cock of the cistern X on P No. 2, causing the steam in that vessel to condense, so that it fills with water while the other empties. The labour of turning the regulator and water cock, and tending the fire, being no more than a boy can perform for a whole day.

The use of the small boiler D is to replenish the great boiler. For by turning the cock of the small boiler D, all communication is cut off between it and the great force-pipe S, by which means D grows immediately hot. By throwing a little fire on it B No. 2, the water of which boils, and soon gains more strength than the great boiler; so that, the water in D being depressed by its own steam, must necessarily rise through the pipe K into L till the surface of the water in D is even with the bottom of the pipe H.

wheel T is fixed; about four feet in diameter. It is shown separately, as in front, *a, b, c, d* are four cleats, all or any number of which may be fixed on the wheel at a time. Each cleat has its correspondent block, *e, f, g, h* on the opposite surface of the wheel. The use of these is to work the engine. Thus, suppose the wheels are turning round, one of the cleats, *a*, meets a lever, which it lifts, and this opens the steam-valve D by a rod reaching the handle of the axis K. The steam consequently passes into the receiver A, and the steam-valve shuts again as soon as the cleat *a* has passed by. In the meantime, the correspondent block *e* on the other side of the wheel T had been raising the loaded lever which forms the handle of the forcing-pump. And at the instant the valve D is shut, the block *e* lets go the loaded lever to descend suddenly by its own weight. This depresses the forcer of the pump, and thereby throws a jet of cold water up into the receiver A, to condense the steam, and make a vacuum therein. The pressure of the atmosphere upon the water in the cistern H then causes it to mount up the perpendicular pipe, through the valve at G, to the exhausted receiver.

When the engine is first set to work, the water-wheel being motionless, the steam-valve and injection-pump are moved by hand; and if the engine has been long out of work, two or three strokes may be necessary to raise water enough to fill the receiver A. As soon as this is done, and the valve is opened to admit steam into the receiver, the whole water above the spout and valve F flows out of the receiver A into the upper cistern.

The Atmospheric Steam-Engine of Newcomen and Cawley.

The title of this machine correctly indicates the principle of its action. The effect which it produces is not by the direct and immediate agency of steam, but of the atmosphere. All that the steam does in this engine is merely to make way for the atmosphere, and give effect to its pressure. It is therefore necessary to retrace our steps, and give some consideration to the operation of such pressure, as an introduction to this description. A full exposition of the pressure of the atmosphere will be found in the article Pneumatics, in the *Encyclopædia Britannica*. We shall only touch upon such branches of experiment here as are closely interwoven with our more immediate investigation.

After the discovery of the laws of atmospheric pressure by the pupils of Galileo, we owe most of our information on the phenomena resulting from that pressure, and of the apparatus for exhibiting its powers on a large scale, to Otto Guericke, privy-councillor of the Elector of Brandenburg, and consul of Magdeburg, who had in 1654 brought his apparatus to considerable perfection, and continued to make experiments to an advanced age. They were published by Gasparas Schottus in his work "De Arte Mechanicâ Hydraulicâ Pneumaticâ," in 1657, and again by the author himself, in a thin volume, entitled "Ottonis Guericke Experimenta Nova Magdeburgica de Vacuo Spatio, Aeris Pondere," &c. Amstelodami, 1672, fol.

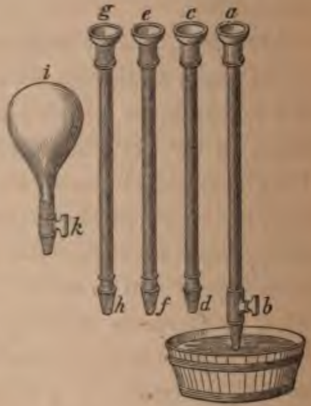
We have translated the following passages of this rare work from a copy in the Physicians' library at Edinburgh. They show that the mode of raising water by atmospheric pressure and a vacuum, was by him so clearly made known, that the use of steam for effecting that vacuum was a very direct and easy transition. Indeed the apparatus we have first to consider is a very simple illustration of the action of Savery's machine.

Illustration of raising water by a vacuum, and the pressure of the atmosphere, from chapter xx. of Guericke.

"Make four tubes or pipes *ab*, *cd*, *ef*, *gh*, each about eight feet long, made of glass, and mounted at the extremities with conically tapered fittings, so as to be accurately joined to each other, each joint surrounded by a small cup, into which liquor being poured, the joints may be prevented from taking in air; let there also be a stopcock on the lowest, and let there be taken a glass flask *i*, also fitted air-tight with a stopcock *k*.

"Having joined all these tubes together, so as to form a tube erected on the wall of a house, the lower end being immersed under water in the open vessel; the large flask or receiver having been previously emptied of air by the air-pump, and being now placed on the top of the long tube, and the stopcock *k* being opened, the water will violently rush up the tube to the height of above thirty feet. The rationale is this, that the external air presses on the surface of the water in the bucket, which finds free exit from this force up the vacuous space of the tube, from which the air has been withdrawn, into the flask *i*; and settles at such a height as will balance by the weight of the column of water the weight of circumambient air."

Fig. 17.

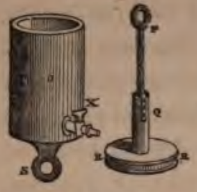


The reader of this very clear and accurate exposition may easily perceive that when it has once been discovered how water, after having been rarefied by heat into steam, so as to fill a large space, can be again condensed by cold, so as to leave a portion of that space vacuous; nothing remains to be done except to make the vacuum of the flask *i* by steam instead of an air-pump, and the machine of Savery is obtained. In fact, the flask *i* of Otto Guericke corresponds to the receiver of Thomas Savery. The reader has only to understand the former, in order to perceive at a glance the action of the latter.

This first experiment of Otto Guericke, therefore, represents with fidelity the principle of Savery's engine for raising water by the formation of a vacuum. Not less beautifully does another experiment of the same philosopher exemplify the principle of the species of engine known as the atmospheric engine, or Newcomen's steam-engine. Its construction is peculiarly important at this stage of our progress, as the reader has only to follow the details of the experiment of Guericke, to comprehend correctly the machine of Newcomen. In fact, all his experiments on the power of the atmosphere are admirable illustrations of the principle of the atmospheric steam-engine; so that the reader will do well to remember that the only use of the steam in the atmospheric steam-engine is to form a vacuum.

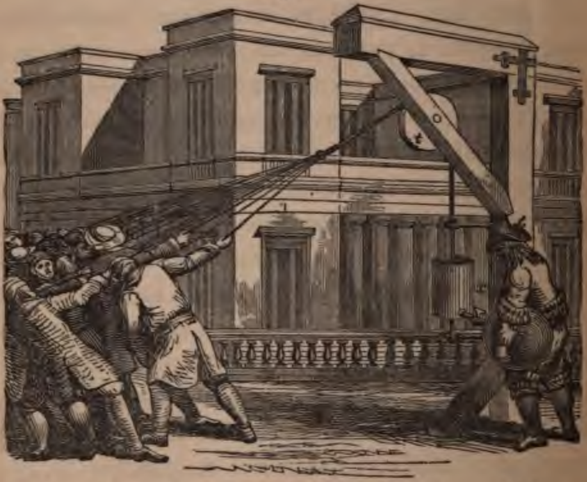
Description of the apparatus for raising weights by a vacuum under a piston in a cylinder, exhibited amongst other experiments, at the diet of Ratisbon in 1654, to the court and his Majesty Ferdinand III. and his son, afterwards Ferdinand IV., &c., chap. xxvii. and xxviii. "A large vessel of copper, *a*, made truly cylindrical,

Fig. 18.



and having its sides perfectly even and parallel, and about twenty inches high and eight inches wide, was fixed firmly in a vertical position by the strong ring S. In the next place, a piston, PQR, was made to fit exactly the inside of the aforesaid cylinder, P being of iron and Q wood, and the rounded head R, formed of the hardest oak, being hollowed out on the edge like the pulley of a common well, in which groove flax or hemp is to be rolled round so as to fill it up, and the whole is then to be placed in the aforesaid cylinder *a*, (like as a piston and its head in a common syringe or pump for extinguishing fires,) and fitted so exactly that air can neither pass outwards or inwards through between the piston and cylinder. Thirdly, the cylinder *a* is to be attached to the great upright beam, Fig. 19, by

Fig. 19.



an iron bracket, through the ring aforesaid S, and the piston PQR is to be let into the cylinder *a*, and the iron handle PQ of the piston is to be passed through the ring of a second iron arm O, in such a manner that it can play freely up and down through the whole height of the cylinder, and at the same time be steadily preserved in the straight line, but not permitted to rise further than O. In the *fourth* place, a rope, to the end of which is firmly attached a hook, is carried round the wheel *t*, and fastened by its hook to the piston rod PQ, and the other end of the rope has other ropes attached to it, to be grasped by the men, as in the figure. Now, if the stopcock X be closed, the piston being nearly at the bottom, the joint efforts of fifty or more men will not be able to raise it more than half-way up the cylinder.

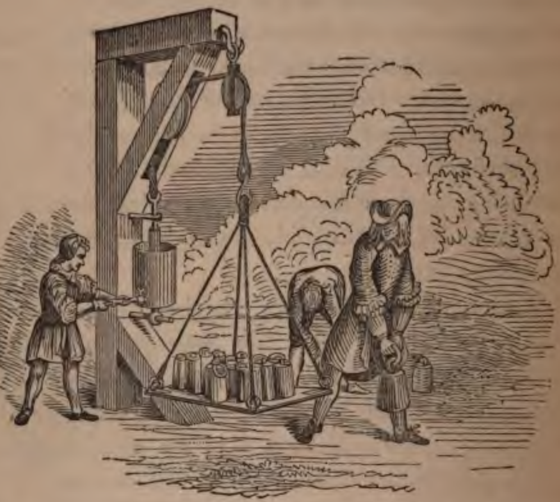
" If, now, in the *fifth* place, the large glass receiver, formerly mentioned, which has been previously made perfectly vacuous, (by an air-pump,) be applied to the stopcock X, and then when the men are exerting their utmost force, the stopcocks at X of the vacuous receiver and the cylinder be opened, so as to make a free communication from the one into the other; the piston PQR will be suddenly forced down to the bottom of the cylinders in spite of the greatest efforts of the men to keep it up.

" The whole cause of this matter is to be attributed to the gravity of the air, which, when the vacuum is formed below, instantly presses down the piston into it with a force which, according to our former calculation, amounts in that size of cylinder to 2686 pounds' weight."

The next of the Magdeburg experiments still more closely resembles the atmospheric steam-engine in its mode of application, and still farther illustrates it.

"By the above-mentioned invention, a child of twelve or fifteen years old can raise an enormous weight. Every thing being left as formerly, only the piston being nearly at the top of the cylinder *a*, you are to pass the rope round a second pulley, hung from a staple as in fig. 20; and by

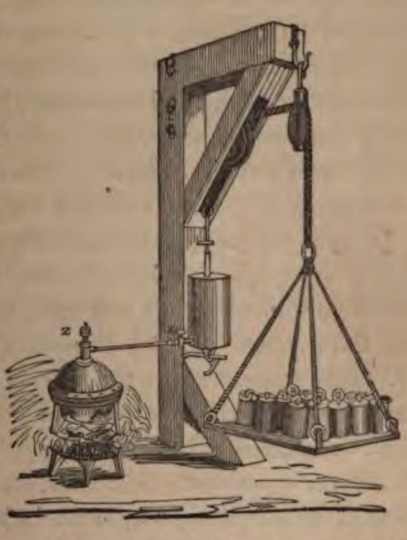
Fig. 20.



a hook to suspend from the rope the scale of a large balance, which you are to load with a weight of 2686 pounds. If a small syringe be applied by a little boy to the stopcock X to pump out the air, it will follow that, as the air is pumped out from below the piston, the atmosphere above will press it down and raise the weight."

The transition from this to the engine of Newcomen is immediate. To the last-described apparatus of Guericke let there be added a small copper globe or boiler, Z, Fig. 21, to be be placed over a fire till water in it boils into steam. This steam, entering below the piston, will drive it up and occupy the whole space of the cylinder; but if now the stopcock X be suddenly closed, and especially if cold water be sprinkled on the outside of the cylinder to cool it, the steam will be condensed back into its original bulk of water, and leave the space it formerly occupied in the cylinder nearly a vacuum, into which the atmosphere will press down the piston as in the former instance, raising up the weights at the other end of the rope. This is just the atmospheric engine of Newcomen: the steam acts indirectly as the medium through which a vacuum is effected; and it is only the agency of the atmosphere which is thus rendered useful in giving motion to a weight.

Fig. 21.



We hope that nothing which we have here said concerning the discoveries of Guericke will be misunderstood, as intended in any way to depreciate the inventions of Mr Savery or Mr Newcomen; they are only introduced as illustrations by which we are most easily conducted to a thorough comprehension of the principles on which they act, and of the state of knowledge of atmospheric pressure at that date. The apparatus of Guericke was in no respect a steam-engine; and although his speculations were divulged before the inventions of Savery and Newcomen, the agency of steam was still required before a useful machine was produced.

Newcomen's Fire-Engine.—Switzer, in his *Hydrostatics,* (1729) says, "I am well informed, that *Mr Newcomen was as early in his invention as Mr Savery was in his,* only the latter being nearer the court, had obtained his patent before the other new it, on which account Mr Newcomen was glad to come in as a partner to it." Dr Desaguliers, speaking of Savery's engine, also says, "these discouragements (the difficulty of making sufficient high-pressure boilers, &c.) stopped the progress and improvement of this engine till Mr Newcomen and John Cawley, brought it to the present form in which it is now used, and has been near these thirty years." (1744.) *Experimental Philosophy,* ii. 467. And again, "about the year 1710, Thomas Newcomen, ironmonger, and John Cawley, glazier, of Dartmouth, in the county of Southampton, (Anabaptists,) made then several experiments in private, and having brought it to work with a piston, &c., in the latter end of the year 1711, made proposals to draw the water at Griff in Warwickshire; but their invention meeting with no reception, in March following, through the acquaintance of Mr Potter of Bromsgrove, in Worcestershire, they bargained to draw water for Mr Back of Wolverhampton, where, after a great many laborious attempts, they did make the engine work. They were at a loss about the pumps, but being so near Birmingham, and having the assistance of so many admirable and ingenious workmen, they soon came to the method of making the *pump-valves, clacks, and buckets;*

whereas they had but an imperfect notion of them before. One thing is very remarkable. At first working, they were surprised to see the engine go several strokes and very quick together, when, after a search, they found a hole in the piston which *let the cold water in to condense the steam in the inside of the cylinder*, whereas, before, they had always done it on the outside. They used before to work with a buoy in the cylinder inclosed in a pipe, which buoy rose when the steam was strong, and opened the injection pipe and made a stroke, whereby they were capable of only giving six, eight, or ten strokes in a minute, till a boy named Humphrey Potter, who attended the engine, added what he called *scoggan, by which the beam of the engine always opened and shut its own valves,* and then it would go (entirely without the attendance of a man) fifteen or sixteen strokes in a minute. But this being perplexed with catches and strings, Mr Henry Beighton, in an engine he had built at Newcastle-on-Tyne in 1718, took them all away, *the beam itself supplying all much better.*

This short note of Dr Desaguliers, who, with Switzer, is our authority for the historical facts of this date, contains the leading points of the history of the steam-engine as generally used for raising water during the eighteenth century. Newcomen gave to the engine a *cylinder and piston :* he formed *a vacuum in the cylinder below the piston* —he gave to the *valves*, *clacks*, *buckets*, *&c.*, that *improved construction* which rendered them suitable to the precision of the action of steam. He first constructed a *piston with an elastic packing* of hemp, by which it is kept steam and air-tight as it moves along the cylinder; and, above all, availed himself of the experience of an unlucky accident to add the important process of *condensing steam by in-*

jecting cold water directly amongst it. All these inventions of Newcomen give to the steam-engine of the present day its most important features.

Fig. 22.

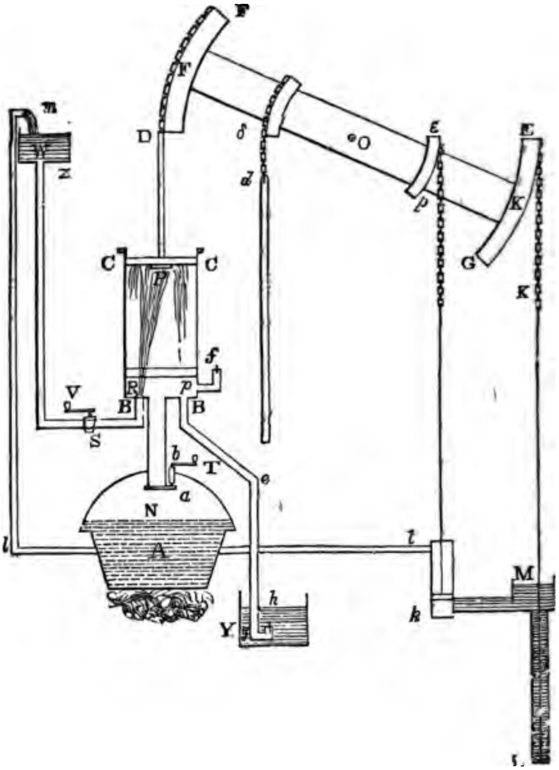


Fig. 22 exhibits the principal parts of Newcomen's engine arranged in a very simple form and without the framing. The following explanation of it will serve as an introduction to the description of the more perfect machine, as given from Smeaton further on.—A represents the boiler, which communicates with the cylinder, CBBC, by the steam-pipe N, the lower end of which is shut by the plate N, called the regulator or steam-cock, which is turned horizontally round an axis *b a* by a handle *b*T.

The piston P, which works in this cylinder, is made air-tight by a packing of hemp, well filled with tallow; and, for greater security, some water is kept above the piston. The piston-rod PD is suspended by a chain from the arch-head FD of the great lever or working beam FK, which turns on the gudgeon O, and to a similar arch-head EG at the other end of the beam is fixed the chain of the pump-rod KL, which raises the water from the mine. The load on this end of the beam is made to exceed considerably the weight of the piston P at the other extremity. A small pump *k l* raises water to the injection cistern W. From this descends the injection-pipe ZSR, which enters the cylinder through its bottom, and terminates in a small hole R, or sometimes in a nozzle pierced with many smaller holes diverging in all directions. In this pipe is the injection-cock S, fitted with a handle V.

At the opposite side of the cylinder is the snifting valve *f*. From the bottom of the cylinder descends the eduction-pipe *p e g h*, by which the water escapes, and of which the lower end being turned upwards, is covered with a valve *h*. This part is immersed in a cistern of water Y, called the hot well. Lastly, the boiler is furnished with a safety-valve.

These are the more essential parts of the engine, in the most simple form. Let us now see how the machine is put in motion, and what is the nature of its work. The water in the boiler being supposed in a state of strong ebullition, and the resting position or attitude of the machine being such as appears in the sketch. Open the steam-cock. The steam will immediately rush into the cylinder, and flying all through it will mix with the air. Much of it will be condensed and wasted by the cold surfaces of the cylinder and piston till they are made as hot as boiling water. When this happens the steam will open the snifting valve *f*, and expel the air from the cylinder.

This being done, and the cylinder fully supplied with steam, the attendant shuts the steam-cock, and opens the injection-cock S. The water by its pressure in the injection-pipe ZS, now begins to enter through the spout R. This coming in contact with the steam in the cylinder begins to condense it, so that it no longer balances the atmospherical pressure on the water in the injection-cistern, and therefore the water spouts rapidly through the hole R, by the joint action of that pressure and the column ZS; at the same time, the snifting-valve *f*, and the eduction-valve *h*, are shut by that pressure. The injection water must therefore be scattered through the whole cylinder. In a very short time, therefore, the condensation of the steam becomes universal, and the elasticity of what remains is almost nothing. The whole pressure of the atmosphere is exerted on the upper surface of the piston, while there is hardly any on its under side. Therefore, if the load on the outer end E of the working-beam be inferior to this pressure, it must yield to it. The piston P must descend, and the pump-piston L must ascend, bringing along with it the water of the mine.

When the piston has descended, the attendant shuts the injection-cock, and opens the steam-cock. The steam having been accumulating in the boiler during the piston's descent, now rushes violently into the cylinder, with an elasticity greater than that of the air. It therefore blows up the snifting-valve, and allows any water which had collected in the cylinder to descend by its own weight through the eduction-pipe *p e g h*, to open the valve *h*, and to run out into the hot well.

Afterwards when Beighton enabled the engine itself to open and shut the other valves, this was principally effected by means of a rod such as *d*, suspended from the beam, and called the plug-tree. It is described with Smeaton's engine, and also among the various methods still used for working the valves.

It was in 1718, as already mentioned, that Mr Henry Beighton improved the steam-engine of Newcomen so much, by a simple and effective arrangement of minor details, that for more than half a century it remained in general use, without any material change. Excellent diagrams and descriptions of these improvements are given by Desaguliers. But it would be superfluous to introduce them here; because they are either repeated or superseded in the descriptions of the more perfect apparatus of Smeaton and others given further on.

Newcomen, Potter, and Beighton, had rendered the atmospheric steam-engine an independent self-acting mechanical power of so great perfection in its principle of action, and its minor details, as to be very generally introduced as a substitute for the power of animals in draining mines and collieries, and to confer very great advantages in those important and primary sources of national industry and wealth. The saving of money from this change was so great as to be continually opening up new avenues of mining enterprise, by the rapid progress of which, the capabilities of the engine were soon put to the severest trial. The cylinders, which had been originally of twelve and sixteen inches diameter, were gradually increased to sixty inches. Along with this dimension, the other parts required to be increased in a still higher proportion; and at last the structures became so gigantic as to demand an amount of science and practical skill which was rare in that period. The man suited to the emergency at last arose in the father of civil engineering, the justly celebrated Smeaton, who brought to bear on this subject endowments and accomplishments seldom united. He conferred upon the atmospheric steam-engine all the extent and variety of application of which it was capable, and all the perfection of proportion and execution which the state of the mechanical arts could then afford.

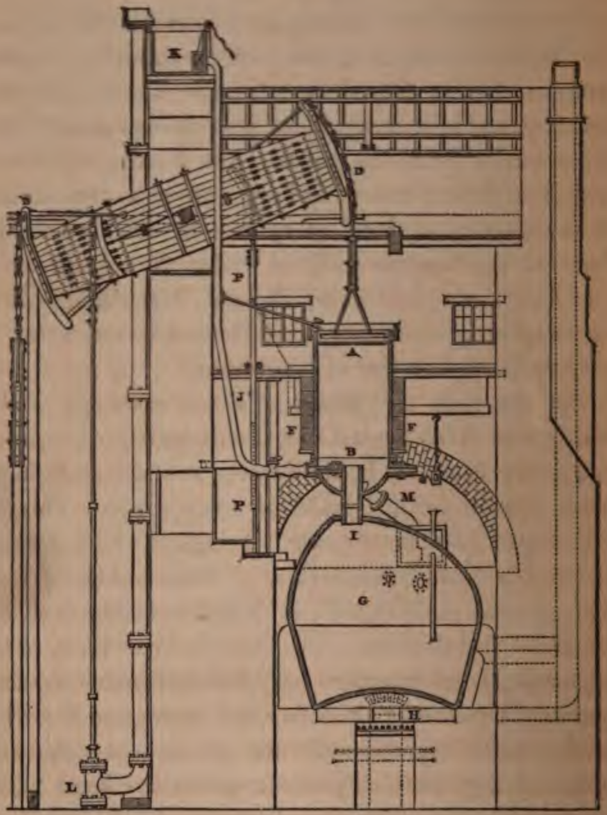
Mr Smeaton produced machines which excelled in their dimensions and efficiency every thing which had preceded them. In 1772 he erected an engine at Long Benton colliery, near Newcastle, which he considered as his standard. The following are its principal statistics: Diameter of cylinder, 52 inches,—7 feet stroke, 12 strokes per minute; being 84 feet useful motion, and 168 total motion per minute. Load of water = 7.1 tons. Load per square inch = 7½ lbs. Consumption of coals, 17.63 lbs. per horse power per hour. Work of one bushel or 84 lbs. of coals = 9.45 millions of lbs. one foot high. The total power of engine was about 40½ horse-power, and for every horse-power the boiler had 52 cubic feet of total space, 27.75 cubic feet of steam room, and 6.25 square feet of horizontal surface of water. The furnace had, for every horse power, 3.5 square feet of fire surface, 7.83 square feet of flue surface, and .867 square foot of fire grate. The total steam produced per minute was about 62.95 feet per horse power; of this 30.58 were used in moving the piston, 8.92 wasted to fill the extra space in the cylinder, and 23.45 condensed on the surface of the cylinder Mr Farey has given an excellent description and investigation of this engine.

Mr Smeaton also constructed a portable fire-engine, for drawing water from temporary excavations, shafts, quarries, &c., so framed as to require no erection of a building, and to be easily shifted from place to place. The fire is wholly within the boiler. The framing of the engine is of timber, trussed and arranged in such a manner as to sustain within itself every kind of strain which the force of the machine and the resistance may produce. The details are given in his Reports; but the high pressure engine is much more portable and better suited to such purposes than that of Newcomen.

But the most magnificent of Smeaton's works in this department is his great Chasewater engine, of which the details are also given in his Reports, and abound in ingenious contrivance and judicious arrangement. This engine was of 150 horses' power, turning out 880 hogsheads of water per hour, by the heat of 16½ bushels of coal. The cylinder A B Fig. 23, is 72 inches in diameter, the stroke 10 feet 6 inches. The great lever or beam of the engine D D, consists of 20 large balks of timber, the four nearest the centre being each a foot square, and the whole firmly joggled together with heart of oak, and bolted with iron, forming a very elegant but ponderous beam. The beams F F, upon which the cylinder rests, are kept in their place by being entered into the side walls of the house, and are joggled and framed together similarly to the great lever. G is the boiler, H the furnace, I B the steam-pipe, J the injection-pipe, K the injection-cistern, fed by a pump

L, which is wrought by the great lever, M the waste-pipe for the condensed steam. On the left edge of the figure is the spear or rod of the great draining-pump, wrought by the engine, P P is the plug-tree suspended from the main beam and carrying plugs, which in their upward and downward progress act on the levers which open and shut

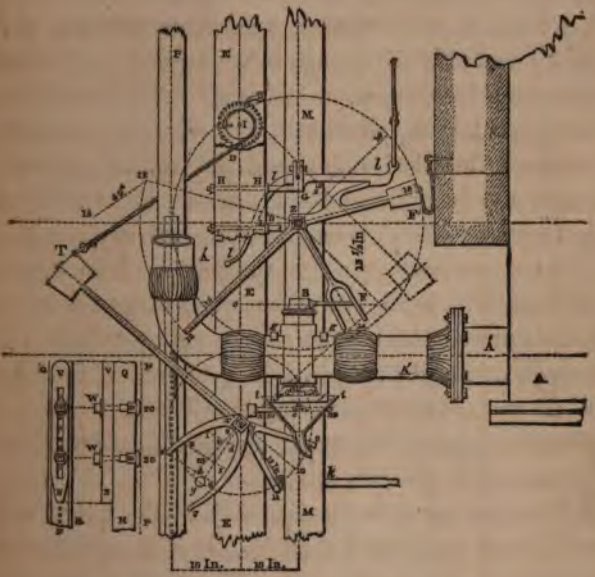
Fig. 23.



the regulator and injection-cocks. The date of this engine is 1775. Its working gear, which is very simple and good, is represented on a larger scale in fig. 24.

A is the lower corner of the cylinder, A′ A′ the injection-pipe, B the injection-cock, B F its handle or spanner passing between the forks of the bent lever E Z F F′, called the F-lever, by which the cock is opened and shut. The tail Z 12 of this F-lever is, by the downward motion of the plug-tree P, forced from the position shown by the dotted line Z 18, into the position in which it is seen in the drawing, and it is there retained by the catch *l l l*. While the lever is in this position the injection cock is shut, the steam from the boiler is flowing into the cylinder,

Fig. 24.



and the piston is rising. When the piston has nearly reached the top of its course, an apparatus attached to the plug-frame P, draws up the catch *l l l*, and releases the F-lever, which is forced into the position 18 Z, by the bob or weight 16, carried by its end F′, and the consequent movement of its fork F opens the injection-cock; T *x* 11, 9, is the Y-lever or tumbler, which acts upon the stirrup rod *k* attached to the spanner of the regulator. The range of the tumbler's motion on each side of the perpendicular is regulated by its check-cord T I, which is passed round a roller I, furnished with a paul and ratchet, so that its length may be adjusted. The tumbler is moved by pins in the plug-frame P, acting upon its bent arms, *x* 3, *x* 7.

In the left-hand corner at the bottom of the figure, is a side and front view of a slider, which may be fixed upon the plug-tree instead of the pins, to work the lever. Q R shows a part of the plug-tree, N V the slider, and W 20, W 20 two screws for retaining the slider in its place. By this means the working-stroke may be adjusted much more surely than by the pins or plugs.

The working of the injection-cock by the forked end of the F-lever being found defective, Mr Smeaton afterwards fixed a tooth sector on the lever, which acted upon a toothed wheel, carried by the axis of the injection-cock.

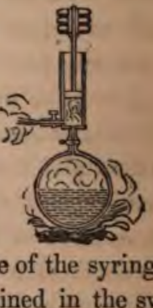
3. *The Era of Watt.*

Before the time of James Watt, the steam or atmospheric engine was a more costly power than horses, except where fuel was extremely cheap. At the mouth of a coal-pit almost any sort of steam-engine or fire-engine is better than horses, because the fuel is the produce, and often the refuse of the pit; and thus the mass of small coals is consumed, which would otherwise lumber the mouth of the pit. The worst sort of engine would raise more coal in twelve minutes than it would consume in twelve hours. In such circumstances, almost any fire-engine is cheaper than the labour of horses. We find that the rudest, most antiquated, worst made, and worst tended engines in the world, are those of Durham coal-fields and around Newcastle, where there are more bad engines than in all the world besides. The reason is obvious; the only constant expense attending the use of these engines is the labour of shovelling in coals. The atmospheric engine, even after it had received all the improvements of three quarters of a century, and attained in the hands of Smeaton all the perfection of which it was capable, still continued an extravagant consumer of coals. Watt was the man who turned the scale of expense so as to give a great preponderance in favour of the fire-engine. In his hands it ceased to be an *atmospheric engine*, and became wholly a *steam-engine*, capable of being applied to an immense variety of purposes, on a much larger scale, and at much less expense than the power of horses, wherever the prices of fuel and of fodder were not in greater disparity than in this country.

We have seen that hitherto the fire-engine, even in Smeaton's hands, was so imperfect that it wasted a large quantity of fuel and of steam in doing what was useless, namely, heating the cylinder, which was cooled alternately in each stroke by the cold water injected into it. In Long Benton colliery engine, out of sixty-three cubic feet of steam, thirty-two were thus wasted, and the remaining thirty-one feet alone performed useful work. There remained, therefore, one-half of the power of the steam and expense of the fuel to be saved by future improvements, provided the useless heating and cooling of the cylinder could be avoided. The vacuum formed below the cylinder was also far from being perfect. In this state Watt found the atmospheric fire-engine in the hands of Smeaton, and produced from it the pure steam-engine which he left to us in its present state of high improvement. The following portion of the history of the steam-engine was contributed by the person best qualified to do it justice, Watt himself, as a commentary upon the original article given in an early edition of the *Encyclopædia Britannica* by Dr Robison. For further illustration, we have added some figures and remarks.

"My attention was first directed in the year 1759 to the subject of steam-engines by the late Dr Robison, himself then a student in the University of Glasgow, and nearly of my own age. He at that time threw out an idea of applying steam to the moving of wheel carriages, and to other purposes; but the scheme was not matured, and was soon abandoned on his going abroad.

Fig. 25.



"About the year 1761 or 1762, I tried some experiments on the force of steam, in a Papin's digester, and formed a species of steam-engine by fixing upon it a syringe one-third of an inch in diameter with a solid piston, and furnished also with a cock to admit the steam from the digester, or shut it off at pleasure, as well as to open a communication from the inside of the syringe to the open air, by which the steam contained in the syringe might escape. When the communication between the digester and syringe was opened, the steam entered the syringe, and by its action upon the piston raised a considerable weight (fifteen lbs.) with which it was loaded. When this was raised as high as was thought proper, the communication with the digester was shut, and that with the atmosphere opened; the steam then made its escape, and the weight descended. The operations were repeated, and though in this experiment the cock was turned by hand, it was easy to see how it could be done by the machine itself, and to make it work with perfect regularity. But I soon relinquished the idea of constructing an engine upon this principle, from being sensible it would be liable to some of the objections against Savery's engine, viz. the danger of bursting the boiler, and the difficulty of making the joints tight, and also that a great part of the power of the steam would be lost, because no vacuum was formed to assist the descent of the piston.

"The avocations of business prevented me from then prosecuting the subject; but in the winter of 1763–4, having occasion to repair a model of Newcomen's engine belonging to the Natural Philosophy Class of the University of Glasgow, my mind was again directed to it. At that period, my knowledge was derived principally from Desaguliers, and partly from Belidor. I set about repairing it as a mere mechanician, and when that was done and it was set to work, I was surprised to find that its boiler could not supply it with steam, though apparently quite large enough; (the cylinder of the model being two inches in diameter, and six inches stroke, and the boiler about nine inches diameter.) By blowing the fire it was made to take a few strokes; but required an enormous quantity of injection water, though it was very lightly loaded by the column of water in the pump. It soon occurred to me, that this was caused by the little cylinder exposing a greater surface to condense the steam, than the cylinders of larger engines did, in proportion to their respective contents. It was found that by shortening the column of water in the pump, the boiler could supply the cylinder with steam, and that the engine would work regularly with a moderate quantity of injection. It now appeared that the cylinder of the model, being of brass, would conduct heat much better than the cast-iron cylinders of larger engines, (generally covered on the inside with a stony crust,) and that considerable advantage could be gained by making the cylinders of some substance that would receive and give out heat slowly. Of these, wood seemed to be the most likely, provided it should prove sufficiently durable. A small engine was therefore constructed, with a cylinder six inches diameter and twelve inches stroke, made of wood, soaked in linseed oil, and baked to dryness. With this engine many experiments were made; but it was soon found that the wooden cylinder was not likely to prove durable, and that the steam condensed in filling it still exceeded the proportion of that required for large engines according to the statements of Desaguliers. It was also found, that all attempts to produce a better exhaustion by throwing in more injection, caused a disproportionate waste of steam. On reflection, the cause of this seemed to be the boiling of water in vacuo at low heats, a discovery lately made by Dr Cullen and some other philosophers, (below 100, as I was then informed,) and consequently, at greater heats, the water in the cylinder would produce a steam which would, in part, resist the pressure of the atmosphere.

“By experiments which I then tried upon the heats at which water boils under several pressures greater than that of the atmosphere, it appeared that when the heats proceeded in an arithmetical, the elasticities proceeded in some geometrical ratio; and by laying down a curve from my data, I ascertained the particular one near enough for my purpose. It also appeared that any approach to a vacuum could only be obtained by throwing in large quantities of injection, which would cool the cylinder so much as to require quantities of steam to heat it again, out of proportion to the power gained by the more perfect vacuum; and that the old engineers acted wisely in contenting themselves with loading the engine with only six or seven pounds on each square inch of the area of the piston. It being evident that there was a great error in Dr Desaguliers' calculations of Mr Beighton's experiments on the bulk of steam, a Florence flask, capable of containing about a pound of water, had about one ounce of distilled water put into it; a glass tube was fitted into its mouth, and the joining made tight by lapping that part of the tube with packthread covered with glazier's putty. When the flask was set upright, the tube reached down near to the surface of the water, and in that position the whole was placed in a tin reflecting oven before a fire, until the water was wholly evaporated, which happened in about an hour, and might have been done sooner, had I not wished the heat not much to exceed that of boiling water. As the air in the flask was heavier than the steam, the latter ascended to the top, and expelled the air through the tube. When the water was all evaporated, the oven and flask were removed from the fire, and a blast of cold air was directed against one side of the flask, to collect the condensed steam in one place. When all was cold, the tube was removed, the flask and its contents were weighed with care; and the flask being made hot, it was dried by blowing into it by bellows, and when weighed again, was found to have lost rather more than four grains, estimated at four and a-third grains. When the flask was filled with water, it was found to contain about seventeen and one-eighth ounces avoirdupois of that fluid, which gave about one thousand eight hundred for the expansion of water converted into steam of the heat of boiling water.

"This experiment was repeated with nearly the same result; and in order to ascertain whether the flask had been wholly filled with steam, a similar quantity of water was, for the third time, evaporated; and, while the flask was still cold, it was placed inverted, with its mouth (contracted by the tube) immersed in a vessel of water, which it sucked in as it cooled, until in the temperature of the atmosphere it was filled to within half an ounce measure of water.

"In repetitions of this experiment at a later date, I simplified the apparatus by omitting the tube, and laying the flask upon its side in the oven, partly closing its mouth by a cork, having a notch on one side, and otherwise proceeding as has been mentioned.

"I do not consider these experiments as extremely accurate; the only scale-beam of a proper size which I had then at my command not being very sensible, and the bulk of the steam being liable to be influenced by the heat to which it was exposed, which, in the way described, is not easily regulated or ascertained; but, from my experience in actual practice, I esteem the expansion to be rather more than I have computed.

"A boiler was constructed, which showed by inspection the quantity of water evaporated in any given time, and thereby ascertained the quantity of steam used in every stroke by the engine, which I found to be several times the full of the cylinder. Astonished at the quantity of water required for the injection, and the great heat it had acquired from the small quantity of water in the form of steam which had been used in filling the cylinder, and thinking I had made some mistake, the following experiment was tried:—A glass tube was bent at right angles, one end was inserted horizontally into the spout of a tea-kettle, and the other part was immersed perpendicularly in well water contained in a cylindric glass vessel, and steam was made to pass through it until it ceased to be condensed, and the water in the glass vessel was become nearly boiling hot. The water in the glass vessel was then found to have gained an addition of about one-sixth part from the condensed steam. Consequently, water converted into steam can heat about six times its own weight of well water to 212°, or till it can condense no more steam. Being struck with this remarkable fact, and not understanding the reason of it, I mentioned it to my friend Dr Black, who then explained to me his doctrine of latent heat, which he had taught for some time before this period, (summer 1764;) but having myself been occupied with the pursuits of business, if I had heard of it, I had not attended to it, when I thus stumbled upon one of the material facts by which that beautiful theory is supported.

"On reflecting further, I perceived that, in order to make the best use of steam, it was necessary, first, that the cylinder should be maintained always as hot as the steam which entered it; and, secondly, that when the steam was condensed, the water of which it was composed, and the injection itself, should be cooled down to 100°, or lower, where that was possible. The means of accomplishing these points did not immediately present themselves; but *early in* 1765 *it occurred to me, that if a communication were opened between a cylinder containing steam, and another vessel which was exhausted of air and other fluids, the steam, as an elastic fluid, would immediately rush into the empty vessel, and continue so to do until it had established an equilibrium;* and if that vessel were kept very cool by an injection, or otherwise, more steam would continued to enter, until the whole was condensed. But both the vessels being exhausted, or nearly so, how was the injection water, the air which would enter with it, and the condensed steam, to be got out? This I proposed, in my own mind, to perform in two ways. One was by adapting to the second vessel a pipe reaching downwards more than thirty-four feet, by which the water would descend, (a column of that length overbalancing the atmosphere,) and by *extracting the air by means of a pump.*

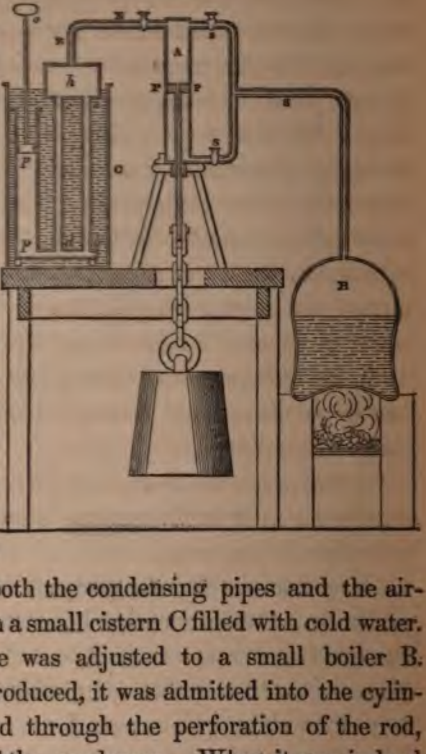
"The second method was *by employing a pump, or pumps, to extract both the air and the water,* which would be applicable in all places, and essential in those cases where there was no well or pit.

"This latter method was the one I then preferred, and is the only one I afterwards continued to use.

"In Newcomen's engine, the piston is kept tight by water, which could not be applicable in this new method; as, if any of it entered into a partially exhausted and hot cylinder, it would boil and prevent the production of a vacuum, and would also cool the cylinder by its evaporation during the descent of the piston. I proposed to remedy this defect by *employing wax, tallow, or other grease, to lubricate and keep the piston tight.* It next occurred to me that the mouth of the cylinder being open, the air which entered to act on the piston would cool the cylinder, and condense some steam on again filling it; I therefore proposed *to put an air-tight cover upon the cylinder, with a hole and stuffing box for the piston rod to slide through,* and to admit steam above the piston to act upon it instead of the atmosphere. There still remained another source of the destruction of steam, the cooling of the cylinder by the external air, which would produce an internal condensation whenever steam entered it, and whic would be repeated every stroke; this I proposed to remedy by *an external cylinder containing steam, surrounded by another of wood, or of some other substance which would conduct heat slowly.*

"When once the idea of the *separate condensation* was started, all these improvements followed as corollaries in quick succession, so that in the course of one or two days, the invention was thus far complete in my mind, and I immediately set about an experiment to verify it practically. I took a large brass syringe A, one and three-fourth inches diameter, and ten inches long, made a cover and bottom to it of tin-plate, with a pipe S to convey steam to both ends of the cylinder from the boiler; another pipe E to convey steam from the upper end to the condenser, (for, to save apparatus, I inverted the cylinder.) I drilled a hole longitudinally through the axis of the stem of P the piston, and fixed a valve at its lower end, to permit the water which was produced by the condensed steam, on first filling the cylinder, to issue. The condenser used upon this occasion consisted of two pipes *a b*, *c d*, of thin

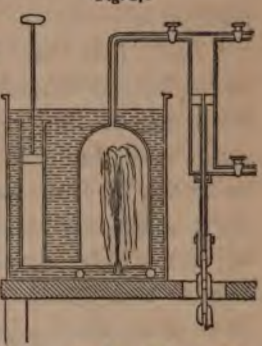
Fig. 26.



tin-plate, ten or twelve inches long, and about one-sixth inch diameter, standing perpendicular, and communicating at top with a short horizontal pipe *h* of large diameter, having an aperture on its upper side which was shut by a valve opening upwards. These pipes were joined at bottom to another perpendicular pipe *p* of about an inch diameter, which served for the air and water pump; and both the condensing pipes and the air-pump were placed in a small cistern C filled with cold water.

"The steam-pipe was adjusted to a small boiler B. When steam was produced, it was admitted into the cylinder, and soon issued through the perforation of the rod, and at the valve of the condenser. When it was judged that the air was expelled, the steam-cock was shut, and the air-pump piston-rod was drawn up, which leaving the small pipes of the condenser in a state of vacuum, the steam entered them and was condensed. The piston of the cylinder immediately rose, and lifted a weight of about eighteen pounds which was hung to the lower end of the piston-rod. The exhaustion-cock was shut, the steam was re-admitted into the cylinder, and the operation was repeated; the quantity of steam consumed, and the weights it could raise were observed; and, excepting the non-application of the steam-case and external covering, the invention was complete, in so far as regarded the savings of steam and fuel. A large model, with an outer cylinder and wooden case, was immediately constructed, and the experiments made with it served to verify the expectations I had formed, and to place the advantage of the invention beyond the reach of doubt. It was found convenient afterwards to change the pipe-condenser for an empty vessel, generally of a cylindrical form, into which an injection played, as in fig. 27, and in consequence of there being more water and air to extract, to enlarge the air-pump.

Fig. 27.



"The change was made, because, in order to procure a surface sufficiently extensive to condense the steam of a large engine, the pipe condenser would require to be very voluminous, and because the bad water with which engines are frequently supplied would crust over the thin plates, and prevent their conveying the heat sufficiently quick. The cylinders were also placed with their mouths upwards, and furnished with a working-beam, and other apparatus, as was usual in the ancient engines; the inversion of the cylinder or rather of the piston-rod, in the model, being only an expedient to try more easily the new invention, and being subject to many objections in large engines.

"In 1768 I applied for letters-patent for my 'Methods of Lessening the consumption of Steam, and consequently of Fuel, in Fire-Engines,' which passed the Seals in January 1769; and my specification was enrolled in Chancery in April following, and was as follows:—

"My method of lessening the consumption of steam, and consequently fuel, in fire-engines, consists of the following principles:—

"First, That vessel in which the powers of steam are to be employed to work the engine, which is called the cylinder in common fire-engines, and which I call the steam-vessel, must, during the whole time the engine is at work, be kept as hot as the steam that enters it; first, by enclosing it in a case of wood, or any other materials that transmit heat slowly; secondly, by surrounding it with steam or other heated bodies; and, thirdly, by suffering neither water or any other substance colder than the steam, to enter or touch it during that time.

"Secondly, In engines that are to be worked wholly or partially by condensation of steam, the steam is to be condensed in vessels distinct from the steam-vessels or cylinders, although occasionally communicating with them; these vessels I call condensers; and, whilst the engines are working, these condensers ought at least to be kept as cold as the air in the neighbourhood of the engines, by application of water, or other cold bodies.

"Thirdly, Whatever air or other elastic vapour is not condensed by the cold of the condenser, and may impede the working of the engine, is to be drawn out of the steam-vessels or condensers by means of pumps, wrought by the engines themselves, or otherwise.

"Fourthly, I intend, in many cases, to employ the expansive force of steam to press on the pistons, or whatever may be used instead of them, in the same manner as the pressure of the atmosphere is now employed in common fire-engines. In cases where cold water cannot be had in plenty, the engines may be wrought by this force of steam only, by discharging the steam into the open air after it has done its office.

"Lastly, Instead of using water to render the piston or other parts of the engines air and steam tight, I employ oils, wax, resinous bodies, fat of animals, quicksilver, and other metals, in their fluid state.

"And the said James Watt, by a memorandum added to the said specification, declared that he did not intend that any thing in the fourth article should be understood to extend to any engine where the water to be raised enters the steam-vessel itself, or any vessel having an open communication with it."

Such is Mr Watt's simple account of his beautiful invention—the condenser or refrigerator, which is the characteristic member of the modern steam-engine. The fire-engine of Newcomen possessed only two principal members, to which all the other parts may be considered as mere appendages. The modern steam-engine of Watt consists of three principal members. The two members of Newcomen's engine are the generating apparatus, by which the steam is produced from the water and conveyed to the second member, or the apparatus of application, where the elastic force of the steam is brought in contact with the piston in the cylinder, so as to produce the motion required for the mechanical effect of the machine, and thus directly applied to the work to be done. The third member, added by Watt, is perfectly distinct from and independent of the other two, namely, a refrigerator or condensing apparatus, for reconverting the steam, after it has done its duty in filling the cylinder, into the liquid from which it had been originally formed. We have, then, the boiler or generator with its appendages, the cylinder or applicator with its appendages, and the refrigerator or condenser with its appendages,—the function to be discharged by the first of these being altogether the reverse of the last; the first producing steam by heat from water, the last producing water from steam by cooling.

Fig. 28.
Papin's Apparatus.

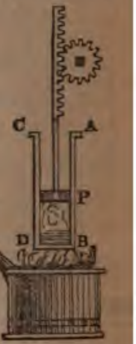
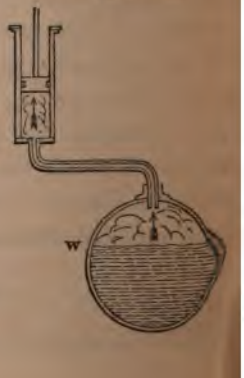
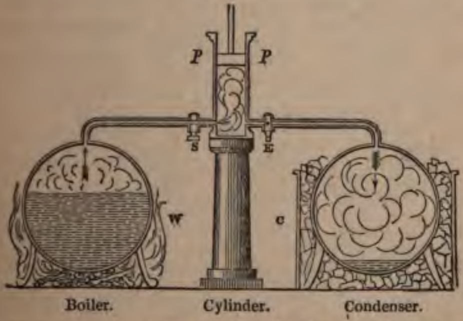


Fig. 29.
Newcomen's Apparatus.



The progress of improvement in the steam-engine may be very well illustrated by comparison with an early project of Dr Papin, who, although he contributed no part towards the production of the modern steam-engine, nevertheless exercised his ingenuity curiously, though fruitlessly, upon the project of deriving mechanical power from the motion of a piston in a cylinder, first of all by gunpowder and afterwards by steam. In Papin's project, fig. 28, he takes a cylinder, A B C D, containing a piston P, below which he places a fire, so as to generate steam from a little water in the bottom of the cylinder. This steam raises the piston, and it is evident that on the fire being removed, steam will be condensed, and the piston will again be carried to the bottom. When with the engine of Newcomen, fig. 29, we compare this rude project of Papin, in which the steam is alternately produced and recondensed in the cylinder itself, which is alternately warmed and chilled, we observe the following important change. The heating of the water and generation of steam are carried on in a boiler, W, now removed to a considerable distance from, and only connected with the cylinder, by a pipe of communication opened and shut alternately. Still, however, we have the process of cooling and condensation wholly carried on in the cylinder itself, by means of a jet of cold water playing therein. But let us now make a third step, and we arrive at the model of a machine acting on the principle of Mr Watt's, fig. 30. As we have already, in the machine of Newcomen, a separate heating apparatus, W, conducting the steam in a highly rarefied state to the cylinder, so now let us have a vessel, C, placed on the other side, and let this vessel have first been rendered empty or perfectly vacuous by expelling and pumping out the air; and let us also, for the sake of experiment, put a few lumps of ice and salt in the inside and on the outside of this vessel, surrounding it on every side; and we shall have a refrigerator as a counterpart to the boiler, and a type of the improvement of Watt.

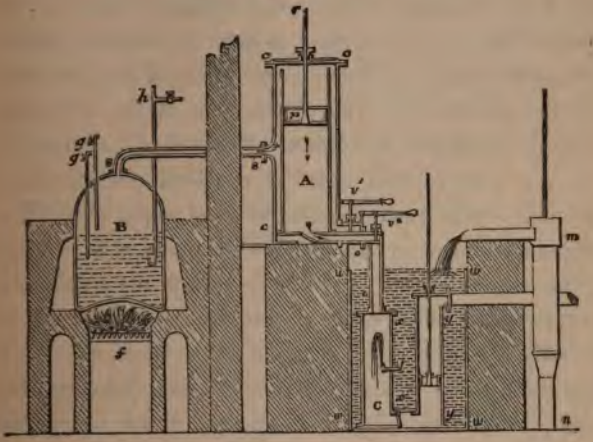
Fig. 30.



If we now open the stopcock S, the steam generated in the boiler will rush into the cylinder, pressing the piston upwards; and if the stopcock E be next opened, the stopcock S having been previously shut, the steam in E will instantly escape into the vacuum in the refrigerator, and being condensed into less than the thousandth part of its bulk, will leave the cylinder vacuous. Thus the motion of the piston upwards and downwards is effected by the inventions of Newcomen and Watt without either applying the fire or the cold directly to the cylinder in which the power is given out. Thus the loss of more than fifty per cent. is avoided by the separate condenser of Watt. Papin's scheme was possible but not practicable; Newcomen's was practicable but wasteful. Watt's engine is practical, economical, and complete, both in theory and in practice, as it renders available all the power of heat which the steam contains, with the exception only of the very small part consumed in giving motion to the machine itself.

Figure 31 approaches very closely to the form of Mr Watt's first engines. Their details are as follows. A represents the cylinder of his earlier engine, B the boiler, and C the condenser, each with its various appendages. The appendages of the boiler B, are of course, *f*, the furnace; *g g*, small pipes for showing the height of the water in the boiler; *h*, a pipe for supplying the boiler with water as it passes off in the form of steam; *s s*, a pipe for conveying the steam to the cylinder. The appendages of the cylinder are, *p*, the piston, fitting accurately the inside of the cylinder, and surrounded with hemp packing, soaked with tallow and oil, so as to be steam-tight; the jacket or casing, *c c c c*, which prevents the cold air of the atmosphere from entering into and cooling the cylinder at the expense of afterwards heating it by the steam; and, instead of allowing such air to enter at the top of the cylinder A, and press down the piston, as in Newcomen's engine, the hot steam is substituted, which, being of an elasticity equal to the force of the atmosphere, presses it towards the bottom of the cylinder. On this being accomplished, the handle of the valve v^1 is raised so as to admit the steam below as well as above the piston; which equilibrium of upward and downward pressure allows the piston again to rise, in consequence of a counter-weight connected with the top of the piston-rod *r;* and this opening of what is called the steam-valve v^1 continues until the piston again reaches the top of the cylinder, when it is closed. The eduction valve v^2, which is at that moment opened, permits the steam to escape suddenly into the condenser, when it becomes water, and leaves the space below the

Fig. 31.



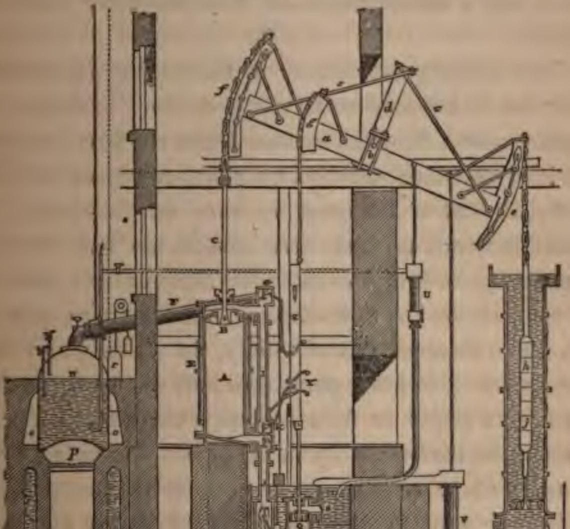
cylinder vacuous, so as to give free space for the piston to be carried down into the cylinder by the pressure of the steam upon the top of the piston. These, the casing, piston, piston-rod, steam-valve, eduction-valve, and communicating passages, are appendages of the second great member of the machine, namely, the cylinder, by which the power of the steam is applied to give the required motion to whatever solid machinery may be placed in connection with the piston-rod. The appendages of the condenser, C, of Mr Watt are as follows. First of all, a large cistern, *w w w w*, of cold water is provided, and furnished continually with fresh supplies of cold water, either from a running stream or by means of a pump *m n*, wrought by the engine itself. In this is placed the condensing chamber C *x x*, wholly surrounded by the cold water, but perfectly empty, excepting that a small jet of cold water from the exterior is admitted through a regulated aperture to play in the inside, by which injection it has always been observed that the condensation of the steam is more efficient than when a casing of metal intervenes between the cold water and the steam. The eduction pipe *e e e*, conducts the steam out of the cylinder by the valve v^2 into the condenser *x x*, where it is reduced back into the water from which it had been originally generated. Now, it must be obvious on a little consideration, that the water which is injected into the condenser must rapidly accumulate there, becoming at the same time warmed by mixing with the steam, and so would impede the process of condensation, by ultimately filling up the interior of the condensing chamber, which should be kept vacuous; and further, that the steam itself, becoming reconverted into water, would soon accumulate in the condenser and choke it up. Hence a principal appendage of the condenser is a large pump, which is essential to its long-continued efficient action, and which withdraws a portion of the accumulated warmed water from the interior of the condenser, and keeps it vacuous; and because there is generally air in the water, and because also air is very apt to insinuate itself by many chinks or crevices into the condenser, this clearing-pump must be capable of pumping out air as well as water. This appendage of the condenser, represented in the preceding figure by *y y*, is generally termed the "air-pump;" a name which but imperfectly expresses its functions.

Fire being placed under the boiler, its heat, communicated to the water, rapidly expands that water, and rarefies it into steam, by the addition of more than five times the heat which would raise its temperature from the freezing to the boiling point. This combination of heat and water, forming the steam, rushes along the steam-pipe into the cylinder casing, and is admitted into the interior of the machine, filling all its chambers and pipes with steam; but that portion of the steam which is in communication with the condenser being instantly chilled by the jet of cold water and the cold sides of the vessels in the cold well, is condensed, and then the valve v^2 being closed so as to admit no more steam into the condenser, and the valve v^1 closed so as to admit no more steam into the lower part of the cylinder below the piston, there remains the elastic force of the steam above, pressing it towards the bottom of the cylinder with a force proportioned to the pressure of the steam and the extent of the cylinder. Thus a moving power is generated in the cylinder by the steam, which may be conveyed through the piston-rod *r*, and applied through various mechanism of application to the performance of the required work. The steam which has thus pressed down the piston is now admitted below to neutralize the force of that which remains; and having thus done its duty, is again annihilated by the opening of the communication into the condenser, into which it rushes, and being almost instantly deprived of the heat which gave it power and magnitude, there remains nothing except the few spoonfuls of water from which all that volume of steam had arisen, now lying inert at the bottom of the cylinder. This dead water is not yet cold. It is evident that in the primary generation of steam in the boiler, the supply of water must be rapidly diminished by this boiling off, and that this water must somehow be supplied. Now here lies an opportunity for economy: this waste, instead of being supplied by cold water, may be better replenished with the water of the condenser, which is highly heated in condensing the steam from the cylinder.

Mr Watt's Engine was first used as a substitute for the engine of Newcomen in pumping up water or draining mines. In 1788 it had attained the form represented in fig. 32, as placed within the walls of a building, the anterior portion of which is omitted to show the machine. On the left stands the boiler outside the building; and on the right, also outside the house, is the large pump, by which the water is raised, and the work of the engine performed. Nearly in the middle stands the cylinder with its appendages, and below these are the cold well and condensing apparatus.

Beginning with the apparatus for generating steam; H is the boiler, of what is called the waggon shape, set in a furnace of brick-work immediately over the fire, which rests on the fire-bars at *p*, over a deep ash pit; the flame passes under the concave bottom of the boiler to the further end, and there, instead of proceeding at once up the chimney, returns by *o* on the left side of the boiler, through the brick channel or flue, giving out additional heat to the water, and after passing across the front of the boiler, proceeds along the right hand flue *o* to the chimney. The draught of the chimney is regulated by the damper *r*, which is lowered into the flue or raised out of it in any degree by the attendant, and so permits the air to rush wit

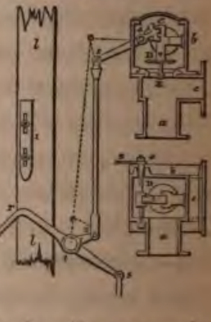
Fig. 32.



greater or less ease up the chimney. A tube *t*, regulated by a stopcock, comes from a small pump U on the right-hand side of the cylinder, which raises the warm water discharged by the air-pump, and sends it into the boiler so as to replenish its waste; this pipe and pump being generally named the feed-pipe and tube. The two little tubes proceeding from the water in the boiler are open at both ends, and have external stopcocks, which are always shut except when the attendant wishes to ascertain the height of the water in the boiler; he then opens these gauge-cocks, and, observing whether water or steam issues from them, forms his judgment accordingly. F is the steam-pipe, which carries the steam from the boiler to the cylinder.

The second great member of the machine, the working cylinder A, is placed in the engine-house. It contains the moving piston B, which communicates the force impressed on it by the steam, through the piston-rod *c*, and the chain *f*, to the end of the great lever or working-beam *f a e*, which is forced up and down around the fixed centre or iron gudgeon *b*, and so raises or depresses the other end of the lever on the right-hand side of the figure, and thus gives the required motion to *h*, *j*, the piston and rods in the barrel of the great pump, in which the work of raising water to a height or from a mine is the useful labour or duty to be performed by the engine. Returning to the cylinder at A, we have now to examine the mechanism by which the steam is admitted alternately above and below the piston, through the openings or ports which may be observed on the right-hand side of the cylinder at top and bottom. F is the steam-pipe which brings steam from the boiler to the top of the valve passages, and the pipe I conducts it down to the bottom valves and port at K, and the pipe J forming the eduction-pipe, conducts the steam into the refrigerating apparatus, where it is finally condensed. In commencing to work the machine, the duty of the attendant is to allow the steam to pass freely into all the pipes, passages, and ports, F G I J, &c. filling the cylinder A, the condenser M, and passing out at an aperture O, closed by a valve called the blow-off valve; by means of which operation, the whole of the parts being filled with steam, are rendered vacuous from air, and this preparatory process is called blowing through. At G is a steam-nozzle and valve, or regulator, which allows the steam to enter the cylinder at the upper part whenever it is opened, by raising the metallic cover or valve from the opening of the nozzle immediately below, which it exactly fits. At K is a similar contrivance called the equilibrium-valve and nozzle, which admits steam through the pipe I into the bottom part of the cylinder; and the third or exhaustion-valve and nozzle or aperture, allows the final egress of the steam into the condenser. After the engine has been wholly filled with steam, the piston B, being at the top of the cylinder, the injection-cock N is suddenly opened, and the cold jet of water playing amongst the steam condenses it instantaneously, forming a vacuum into which the steam from the cylinder instantly rushes, and is in like manner annihilated, leaving the cylinder below the piston equally vacuous; and of course the steam from the boiler, on being admitted by the valve G to the upper side of the piston, instantly presses it down into the vacuum below with a force proportional to the perfection of that vacuum and to the pressure of the steam. Thus the engine makes its first stroke, and raises the water of the great pump on the right of the figure, and the weight of the chain, rod, and bucket, and also a counterpoise *h*, added for restoring the beam to its former position, which it does in the following manner. The equilibrium-valve K is opened, and the steam getting admission below the piston, as well as above it, ceases to urge it in either direction, and being thus *in equilibrio*, the piston would remain passively in its place at the bottom of the cylinder; but the counterpoise *h*, and the weight of the pump-rods and bucket in the large pump on the outside, draw down the outer end of the great lever or working beam *f a e*, and so raise the interior end *f*, and the piston B to the top of the cylinder. The equilibrium-valve is then closed at K, and the eduction-valve L is opened, so as to allow the steam below the piston to rush down into the condenser and leave a vacuum under the piston, into which it is immediately forced down by the pressure of the steam above A as at first, and raising water at the other end of the beam through a second stroke; and thus, by the continual opening and shutting of the valves by the attendant, the engine performs its work. But we have still to consider the mechanism by which the machine shuts and opens its own valves. For this purpose we have given in fig. 33 two separate and enlarged drawings of one of the valves and its working gear:—*l i l* is a part of the air-pump rod, formed of wood, called the plug-frame or plug-tree, on which are two projecting plugs of wood to work the upper and lower valves; one of these plugs is seen at *i*. As the plug-tree moves up and down, the plugs strike the handles or working gear of the valves, and open or shut them at the pro-

Fig. 33.



per instant. The valve D E is called a conical valve, because the small cover D which closes the opening of the nozzle is slightly tapered downwards so as the more readily to fit its seat, from which it is lifted by a small toothed rack and pinion *c* moved by a spindle from without, and communicating by rods with the valve gear at *r*, or at Z and Y in figure 32. When the plug-frame *l i l* descends, the valve D is closed by the plug *i*, and the valve K is shut, and the valve L in figure 32 opened by the plug Y.

Returning to figure 32, where the condensing apparatus and its appendages are placed almost immediately under the cylinder, and to the right of it. The eduction-pipe J conducts the steam into the condensing chamber M, which is in the middle of the cold well, wholly surrounded by cold water; and through the regulated aperture N a jet of cold water pressed in by the atmosphere is allowed to play in the inside of it amongst the steam. P the air-pump is also placed in the cold well surrounded by water; Q the piston or bucket of the air-pump is worked up and down by the piston-rod Q Y Z *g* from the great lever. The valve R closes when the piston descends, and opens on its ascent, allowing water and air to pass into the air-pump, but preventing their return; and the upper valve of the air-pump S allows the escape of water and air outwards, but prevents their return; this valve S leads to the hot well T, from which the feed-pump U supplies water for the boiler.

The great advantage of Mr Watt's form consists in avoiding the excessive waste of steam formerly occasioned by condensing in the cylinder itself. The cylinder now is always hot, and therefore perfectly dry. By the time Mr Watt had completed these improvements, his experiments on steam had given him a pretty accurate knowledge of its density: and he found that the quantity of steam employed did not much exceed what would fill the cylinder, so that very little was unavoidably wasted. But before he could bring the engine to this degree of perfection, he had many difficulties to overcome. He enclosed the cylinder in another containing steam, and that in a wooden case at a small distance from it, which effectually prevented all condensation in the inner cylinder from external influence; and the condensation by the outer cylinder was very small.

"The greatest difficulty was to make the piston tight. The old and effectual method, by water lying on it, was inadmissible. He was therefore obliged to have his cylinders very nicely bored, perfectly cylindrical, and finely polished; and he made numberless trials of different soft substances for packing his piston, which should be tight without much friction, and long remain so in a situation perfectly dry and very hot.

"An engine of this construction, of the same dimensions with an old engine, and making the same number of strokes of the same extent, does not consume above one-fourth *or one-third* of the fuel that was consumed by the best engines of the old form. It is also very fortunate that the performance of the engine is not sensibly diminished by a small want of tightness in the piston. In the old engine, if air thus got in, it immediately put a stop to the work; but here although even a considerable quantity of steam get past the piston, the rapidity of condensation is such, that hardly any diminution of pressure can be observed.

"When Newcomen's engines were working under loads inferior to their whole power, they were regulated by lessening the quantity of injection, or by shutting the injection-cock sooner. The new engines may, in some degree, be regulated in the same manner; but it is done more effectually and economically, first, by limiting the opening of the regulating valve which admits the steam above the piston, and letting it continue so far open during the whole length of the stroke; secondly, by letting it open fully at first, and shutting it completely when the piston has only made part of its stroke; or, lastly, by the use of a throttle-valve, which admits no more steam than gives the desired power.

"The second of these methods forms the basis of what is called the *Expansive Engine*, which renders available the greater part of the power with which the steam would rush into empty space,—a principle which had first occurred to Mr Watt in 1769, and was adopted in an engine at Soho manufactory, and some others about 1776, and in 1788 at Shadwell water-works, and afterwards described in his specification of a patent in 1782.

"The construction of this engine is as has been described. The steam-valve is always allowed to open fully; the pins of the plug-frame are regulated so, that that valve shall shut the moment the piston has descended a certain portion, suppose one-fourth, one-third, or one-half, of the length of the cylinder. Thus far the cylinder is occupied by steam as elastic as common air. In pressing the piston farther down, it behoves the steam to expand, and its elasticity to diminish. It is plain that this can be done in any degree we please, and that the adjustment can be varied in a minute, by shifting the plug-pins.

"In the meantime, the pressure on the piston is continually changing, and consequently the accelerating force.

The motion, therefore, will no longer be uniformly accelerated. It will approach much faster to uniformity; nay, it may be retarded, because although the pressure on the piston at the beginning of the stroke may exceed the resistance of the load, yet, when the piston is near the bottom, the resistance may exceed the pressure.

" We shall give here Mr Watt's theory of the expansive engine.

" Let ABCD (fig. 34.) represent a section of the cylinder, and EF the surface of its piston. Let us suppose that the steam was admitted while EF was in contact with AB, and that as soon as it had pressed it down to the situation EF, the steam-cock is shut. The steam will continue to press it down, and as the steam expands, its pressure diminishes. We may express its pressure (exerted all the while the piston moves from AB to EF) by the line EF. If we suppose the elasticity of the steam proportional to its density, as is the case with air, (when its temperature is constant), we may express the pressure on the piston in any other position, such as KL or DC, by K *l* and D *c*, the ordinates of a rectangular hyperbola F *l c*, of which AE, AB are the asymptotes, and A the centre. The accumulated pressure during the motion of the piston from EF to DC, will be expressed by the area EF*c*DE, and the pressure during the whole motion by the area ABF*c*DA.

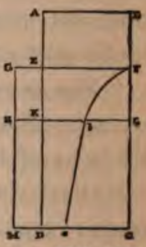


Fig. 34.

" Now the area EF*c*DE is equal to ABFE multiplied by the hyperbolic logarithm of $\frac{\text{AD}}{\text{AE}}$, or by $\text{L.}\frac{\text{AD}}{\text{AE}}$, and the whole area ABF*c*DA is $= \text{ABFE} \times \left(1 + \text{L.}\frac{\text{AD}}{\text{AE}}\right)$.

"Thus let the diameter of the piston be 24 inches, and the pressure of the atmosphere on a square inch be 14 pounds; the pressure on the piston is 6333 pounds. Let the whole stroke be 6 feet, and let the steam be stopped when the piston has descended 18 inches or 1.5 feet. The hyperbolic logarithm of $\frac{6}{1{\cdot}5}$ is 1.3862943. Therefore the accumulated pressure ABF*c*DA is $= 6333 \times 2.3862943$, $= 15112$ pounds.

"As few professional engineers are possessed of hyperbolic logarithms, while the common logarithms are, or should be, in the hands of every person who is much engaged in calculations, let the following method be practised. Multiply the common logarithm of $\frac{\mathrm{AD}}{\mathrm{AE}}$, by 2.3026; the product is its hyperbolic logarithm.

"The accumulated pressure while the piston moves from AB to EF, is 6333 × 1, or simply 6333 pounds. Therefore the steam while it expands into the whole cylinder adds a pressure of 8781 pounds.

"Suppose that the steam had got free admission during the whole descent of the piston, the accumulated pressure would have been 6333 × 4, or 25332 pounds.

"Here Mr Watt observed a remarkable result. The steam expended in this case would have been four times as great as when it was stopped at one-fourth, and yet the accumulated pressure is not twice as great, being nearly five-thirds. One-fourth of the steam performs nearly three-fifths of the work, and an equal quantity performs more than twice as much work when thus admitted during one-fourth of the motion.

"This is curious and important information, and the advantage of this method of working a steam-engine increases in proportion as the steam is sooner stopped; but the increase is not great after the steam is rarefied four times.* The curve approaches near to the axis, and small additions are made to the area. The expense of such great cylinders is considerable, and may sometimes compensate this advantage.

"It is very pleasing to observe so many unlooked-for advantages resulting from an improvement made with the sole view of lessening the waste of steam by condensation. While this purpose is gained, we learn how to husband the steam which is not thus wasted. The engine becomes more manageable, and is more easily adapted to every variation in its task, and all its powers are more easily computed.

Let the steam be stopped at	Its performance is mult.
$\frac{1}{2}$	1.7
$\frac{1}{3}$	2.1
$\frac{1}{4}$	2.4
$\frac{1}{5}$	2.6
$\frac{1}{6}$	2.8
$\frac{1}{7}$	3.
$\frac{1}{8}$	3.2
&c.	&c.

---

* But in these calculations no allowance has been made for the pressure of the steam (as well as that of air and other elastic fluids when suddenly dilated,) decreasing much more rapidly than in proportion to the density; owing to the fall of temperature which necessarily attends such a rapid and great dilatation as the steam is here to undergo, and which must greatly lessen its effect on the engine. Still, however, unless the expansive system be carried to excess, it is the most advantageous method of using the steam, especially when of high pressure; not only because it renders

"The active mind of its ingenious inventor did not stop here. It had always been matter of regret that one-half of the motion was unaccompanied by any work. It was a very obvious thing to Mr Watt, that as the steam admitted above the piston pressed it down, so steam admitted below the piston would press it up with the same force, provided a vacuum were made on its upper side. This was easily done, by connecting the lower end of the cylinder with the boiler and the upper end with the condenser."

Hitherto we have considered the condensing steam-engine of Watt as applied to work the large pumps used to draw water from mines or to supply reservoirs from a lower level. This, indeed, was the most obvious and immediate application of the steam-engine which was at first introduced as a substitute for the atmospheric pumping engine of Newcomen.

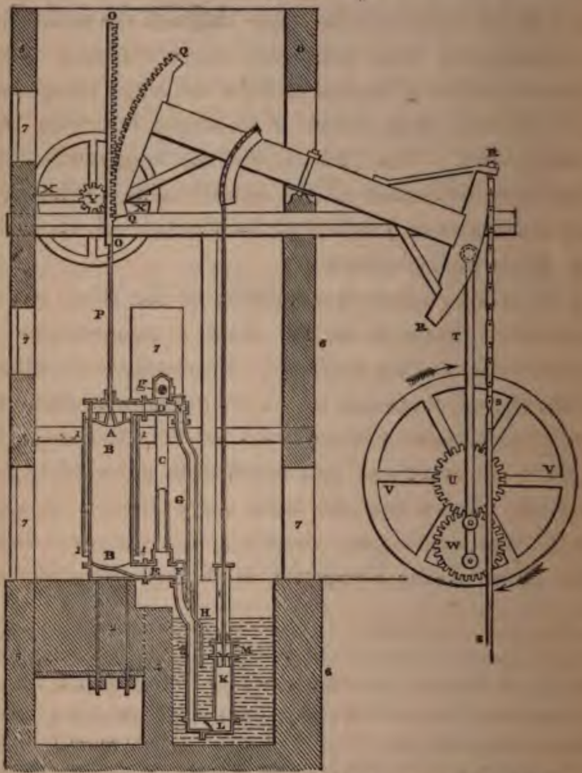
The steam-engine of revolution of Mr Watt was an invention subsequent to the mining steam-engine or "water-commanding machine." Previously to the time of Watt, indeed, there had been a few attempts to produce a revolving motion by steam, such as the case where the engines of Savery and Newcomen drew up water to turn a wheel. There had also been many attempts to apply the old pumping engine directly to this purpose—Jonathan Hulls, Keane Fitzgerald, Mr Oxley, John Stewart,

available most of its force, but because that variable force may be proportioned to equalize considerably the action of the engine. For at the beginning of each stroke, a great effort is required to overcome the inertia of the beam or of any parts having a corresponding reciprocating motion; whereas in the latter part of the stroke, the momentum which those reciprocating parts have acquired, is almost sufficient to continue the motion of the engine without the aid of the steam.

and Matthew Wasbrough, had all contrived some means of producing a revolving motion from the reciprocation of the great beam; but Watt's engine alone was capable of being rendered an efficient and economical motive power. The following is his method of applying it to any machine of the rotatory kind.

"VV, fig. 35, represents a very large and heavy fly.

Fig. 35.



On its axis is the concentric-toothed wheel U. There is attached to the end of the great beam a strong rod T, to the lower end of which a toothed wheel W is firmly fixed by two bolts, so that it cannot turn round. This wheel is of the same size and in the same plane with the wheel U; and an iron link or strap (which cannot be seen here) connects their centres, so that the one cannot quit the other. The engine being in the position represented in the figure, suppose the fly to be turned once round by any external force in the direction of the darts. It is plain, that since the toothed wheels cannot quit each other, the inner half (or that next the cylinder) of the wheel U will work on the outer half of the wheel W, so that at the end of the revolution of the fly, the wheel W must have got to the top of the wheel U, and the outer end of the beam must be raised to its highest position. The next turn of the fly will bring the wheel W and the beam to their first positions; and thus every two revolutions of the fly will make a complete period of the beam's reciprocating movements. Now, instead of the fly driving the beam, let the beam drive the fly. The motions must be perfectly the same, and the ascent or descent of the piston will produce one revolution of the fly.

"It is proper here to give the history of this invention. I had very early turned my mind to the producing continued motions round an axis, and it will be seen by reference to my first specification in 1769, that I there described a steam-wheel, moved by the force of steam acting in a circular channel against a valve on one side, and against a column of mercury or some other liquid metal on the other side. This was executed upon a scale of about six feet diameter at Soho, and worked repeatedly, but was given up, as several practical objections were found to operate against it. Similar objections lay against other rotative engines which had been contrived by myself and others, as well as to the engines producing rotatory motions by means of ratchet-wheels. Having made my reciprocating engines very regular in their movements, I considered how to produce rotative motions from them in the best manner; and amongst various schemes which were subjected to trial, or which passed through my mind, none appeared so likely to answer the purpose as the application of the crank in the manner of the common turning lathe, (an invention of great merit, of which the humble inventor, and even its era, are unknown.) But, as the rotative motion is produced in that machine by the impulse given to the crank in the descent of the foot only, and behoves to be continued in its ascent by the momentum of the wheel, which acts as a fly, and being unwilling to load my engine with a fly heavy enough to continue the motion during the ascent of the piston, (and even were a counterweight employed to act during that ascent of a fly heavy enough to equalize the motion,) I proposed to employ two engines acting upon two cranks fixed on the same axis at an angle of one hundred and twenty degrees to one another, and a weight placed upon the circumference of the fly at the same angle to each of the cranks, by which means the motion might be rendered nearly equal, and a very light fly only would be requisite. This had occurred to me very early; but my attention being fully employed in making and erecting engines for raising water, it remained *in petto* until about the year 1778 or 9, when Mr Wasbrough erected one of his ratchet-wheel engines at Birmingham, the frequent breakages and irregularities of which recalled the subject to my mind, and I proceeded to make a model of my method, which answered my expectations; but having neglected to take out a patent, the invention was communicated by a workman employed to make the model to some of the people about Mr Wasbrough's engine, and a patent was taken out by them for the application of the crank to steam-engines. This fact the said workman confessed, and the engineer who directed the works acknowledged it, but said, nevertheless, the same idea had occurred to him prior to his hearing of mine, and that he had even made a model of it before that time, which might be a fact, as the application of a single crank was sufficiently obvious. In these circumstances I thought it better to endeavour to accomplish the same end by other means, than to enter into litigation, and if successful, by demolishing the patent, to lay the matter open to every body. Accordingly, in 1781, I invented and took out a patent for several methods of producing rotative motions from reciprocating ones, amongst which was the method of the sun and planet wheels above described.

"This contrivance was applied to many engines, and possesses the great advantage of giving a double velocity to the fly; but is perhaps more subject to wear, and to be broken under great strains, than the crank, which is now more commonly used, although it requires a fly-wheel of four times the weight, if fixed upon the first axis. My application of the double engine to these rotative machines rendered unnecessary the counter-weight, and produced a more regular motion; *so that, in most of our great manufactories, these engines now supply the place of water, wind, and horse mills; and instead of carrying the work to the power, the prime agent is placed wherever it is most convenient to the manufacturer.*"

"Let us now trace the operation of this machine through all its steps. Let us suppose that the lower part of the cylinder BB, fig. 35, is exhausted of all elastic fluids; that the upper steam-valve D and the lower eduction-valve F are open, and that the lower steam-valve E and upper eduction-valve N are shut. It is evident that the piston must be pressed toward the bottom of the cylinder, and must pull down the end of the working-beam by means of the toothed rack OO and sector QQ, causing the other end of the beam to urge forward the machinery with which it is connected. When the piston arrives at the bottom of the cylinder, the valves D and F are shut by the plug-frame, and E and N are opened. By this last passage the steam gets into the eduction-pipe, where it meets with the injection water, and is rapidly condensed. The steam from the boiler enters at the same time by E, and pressing on the lower side of the piston, forces it upwards, and by means of the toothed rack OO and toothed sector QQ forces up that end of the working-beam, and causes the other end to urge forward the machinery with which it is connected; and in this manner the operation of the engine may be continued.

"The injection water is continually running into the eduction-pipe, because condensation is continually going on, and therefore there is a continual atmospheric pressure to produce a jet. The air which is disengaged from the water, or enters by leaks, is evacuated only during the rise of the piston of the air-pump K.

"It is evident that this form of the engine, by maintaining an almost constant and uninterrupted impulsion, is much fitter for driving any machinery of continued motion than any of the former engines, which were inactive during half of their motion. It does not, however, seem to have this superiority when employed to draw water; but it is also fitted for this task. Let the engine be loaded with twice as much as would be proper for it if a single stroke engine, and let a fly be connected with it. Then it is plain that the power of the engine during the rise of the steam-piston will be accumulated in the fly; and this, in conjunction with the power of the engine during the descent of the steam-piston, will be equal to the whole load of water."

Mr Watt had forgotten the date of the invention of the double acting engine of revolution, but a drawing of it was produced in the House of Commons in 1774.

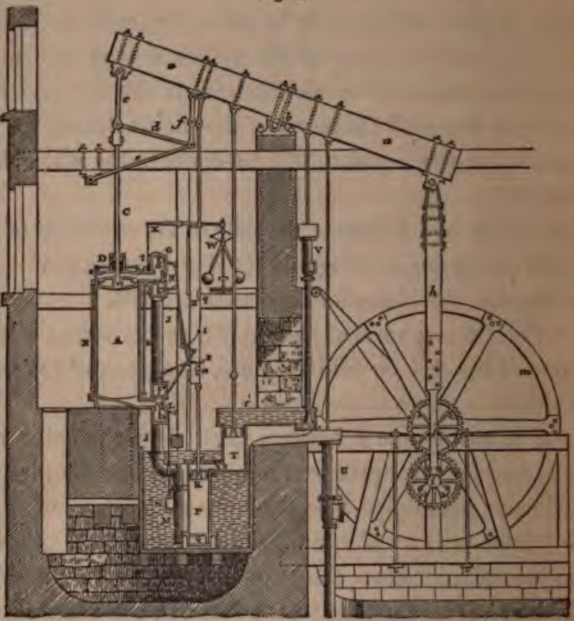
"Fig. 36 is a vertical and fig. 37 an horizontal section of one of the Albion Mill Engines, being one of the earliest double engines made for sale.

"The steam-pipe F conveys steam from the boiler *n* to the cross-pipe, or upper steam-nozzle G, and by the perpendicular steam-pipe I, to the lower steam-nozzle K. In the nozzle G is a valve, which, when open, admits steam into the cylinder *above* the piston B, (fig. 36,) through the horizontal square pipe at its top; and in the *lower* steam-nozzle K there is another valve, which, when open, admits steam into the cylinder *below* the piston. In the upper exhaustion-nozzle H is a valve, which, when open, admits steam to pass from the cylinder *above* the piston into the exhaustion-pipe J, which conveys it to the condensing-vessel M, where it meets the jet of the injection from the cock N, and is reduced to water; and, in the *lower* exhaustion-nozzle L, there is also a valve, which, when open, admits steam to pass out of the cylinder *below* the piston, by the eduction-pipe, into the condenser M.

"The piston being at the top of its stroke, the valves

G and L are to be opened, and the fly-wheel *m* turned by hand about the eighth of a revolution, or more, in the direction in which it is intended to move; the steam which is then in the cylinder will pass by L into the condenser, when, meeting the jet of water from the injection-cock, it will be converted into water, and the cylinder thus becoming exhausted, the steam, entering the cylinder by the valve G, will press upon the piston and cause it to descend, while, by its action upon the working-beam through the piston rod, &c., it pulls down the cylinder-end of the beam, and raises up the outer-end and the connecting rod *h*, which causes the planet-wheel *i* to tend to revolve round the sun-wheel *j*; but the former of these wheels, being

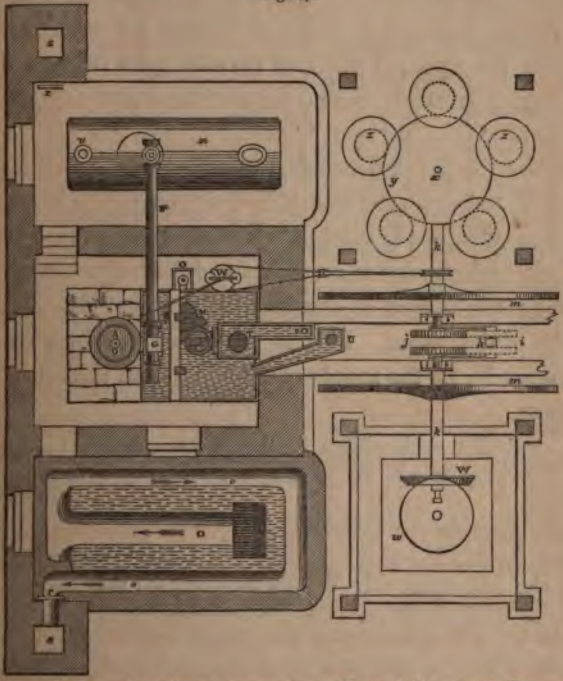
Fig. 36.



fixed upon the connecting-rod so that it cannot turn upon its own axis, and its teeth being engaged in those of the sun-wheel, the latter, and the fly-wheel, upon whose axle or shaft it is fixed, are made to revolve in the desired direction, and give motion to the mill-work.

"As the piston descends, the plug-tree Z also descends, and a clamp, or slider *q*, fixed upon the side of the plug-tree, presses upon the handle 1 of the upper Y-shaft, or axis, and thereby shuts the valves G and L; and the same operation, by disengaging a detent, permits a weight suspended to the arm of the lower Y-shaft to turn the shaft upon its axis, and thereby to open the valves K and H.

Fig. 37.



Just before the opening of these valves, the piston had reached the lowest part of its stroke, and the cylinder *above* the piston was filled with steam; but as soon as H is opened, that steam rushes, by the eduction-pipe J, into the condenser, and leaves the cylinder empty *above* the piston. The steam from the boiler entering by I and K, acts upon the *lower* side of the piston, and forces it to return to the top of the cylinder. When the piston is very near the upper limit of its stroke, another slider *a* raises the handle 2, and in so doing disengages the catch, which permits the upper Y-shaft to revolve upon its own axis and open the valves G and L, and the downward stroke recommences as has been related.

When the piston descends, the buckets R, T of the air-pump P and hot-water pump T also descend. The water which is contained in these pumps passes through the valves of their buckets, and is drawn up and discharged by them through the lander or trough *t*, by the next descending stroke of the piston. Part of this water is raised up by the pump V, for the supply of the boiler, and the rest runs to waste.

The reader who wishes further details concerning the steam-engine of Mr Watt, will find them in the descriptive portion of this treatise, in the sequel.

The history of the steam-engine in a great measure ends with the history of Mr Watt's labours. There are, it is true, many parts of the steam-engine that have been altered, simplified, or adapted to peculiar uses and circumstances since his time; but these are matters of minor importance, without which the engine would not have been materially curtailed of its present efficiency. It is a remarkable fact that the steam-engine has scarcely received any very valuable improvement since his time. He, in fact, rendered it a machine nearly perfect. The testimony of Mr Farey upon this subject is explicit, and must be conclusive on the subject with every one who has the means of ascertaining the very high estimation to which the knowledge and practical skill of that excellent writer on the steam-engine most justly entitle him. "It is a circumstance," says Mr Farey, (*Steam-Engine, p.* 473,) "highly creditable to Mr Watt's character, both as an original inventor and as a practical engineer, that his first double-revolving engine, which he made in 1787 at the Albion Mills, performed quite as well as any engine which has since been constructed to employ steam on the same principles. Some important improvements have been made in the construction of modern engines by substituting cast-iron and stone-work in the place of wood, and by putting the parts together in more substantial modes; but all those essential forms and proportions which affect the performance of the machine, were so ascertained by the first inventor, that no improvement has been since made in them, and every departure from those forms and proportions has impaired the performance in a greater or less degree."*

Thus have we taken a rapid survey of the history of the steam-engine. We have omitted the names of many individuals who have distinguished themselves by ingenuity directed to this subject. We have omitted the labours of Gebert, Alberti, Cardan, De Caus, Branca, Morland, Papin, Amonton, Leupold, Meyer, Bosfrand, Gessanne, and a hundred others who have, all in different degrees, expended ingenuity upon the application of steam to the production of mechanical power; and these we have omitted, not because we consider their labours either undeserving of notice or uninteresting to the general reader, but because they have not contributed towards the production of the modern steam-engine, and because an account of their works would rather serve to illustrate the possible varieties of the machine and the fertility of the human mind in mechanical devices, than either to conduct the reader along the stream of historical succession, or render him better acquainted with the nature and mechanical peculiarities of the steam-engine itself.

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* In the specifications of Mr Watt's patents are included various inventions which have been brought forward by others as new, at more recent dates; as for instance, the direct acting steam hammer patented in 1806 by Mr Deverell; and again in 1843 by Mr Nasmyth, who has no small merit in having put it in practice on a grand scale and with great success, both as a forge hammer and also as a pile driver. In simplicity, docility, and efficiency, it greatly excels any former methods of moving hammers by steam.

PART II.—DESCRIPTION OF THE MODERN STEAM-ENGINE.

Of modern steam-engines there are two distinct species —the high-pressure and low-pressure engines. The former is simple, light, and of few parts, generally used for locomotive engines, steam-carriages, steam-vessels of a light and rapid construction, and such other purposes as require portability or cheapness. The latter is more complex, but more effective; more expensive in original construction, but more durable and more economical in consumption of fuel. The first is more commonly used in America, the latter in this country. The high-pressure engine is sometimes also called the non-condensing steam-engine, to distinguish it from the low-pressure engine, which is also called the condensing steam-engine: but there is sometimes a combination effected of some of the parts and principles of both these species, in what is called a high-pressure condensing engine, by which, for certain purposes, the peculiar merits of both species are combined in the same machine.

Of these two sorts of steam-engine, it is remarkable that the more elementary and simple—that which is the more easily conceived and understood—was not brought into practical use until long after the other kind had been very extensively used and made known by its inventor, James Watt. It appears to us, that we are to consider OLIVER EVANS of Philadelphia as the first constructor of the modern high-pressure engine.* Before 1786 he had erected and made experiments upon a high-pressure engine, which seems to have been in all essential respects similar to our own. Indeed, it appears that the Americans have taken the form and arrangements of their engines from Evans, as implicitly as in this country we have adopted those of Watt. The history of Evans consists almost entirely of the romance of real life. Sanguine and energetic, he continually encountered difficulties only to overcome them, and to encounter renewed disaster and disappointment, till he at length died of a broken heart. To him we attribute the rapid advancement of America, at the commencement of the present century, in all that relates to the introduction of the steam-engine in its multifarious applications, and especially in steam navigation. He had awakened in that nation a lively sense of the advantages they were likely to derive from the power of steam, and placed in their hands an instrument well fitted for their use, and which they were not slow to adopt and apply.

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* Evans' title to priority in this invention must be restricted to his putting it in practice; because Mr Watt had previously included it in the specifications of his patents.

The high-pressure or non-condensing engine consists of *two* principal members, *generator* or *boiler* and working *cylinder*, each with sundry appendages. The low-pressure or condensing steam-engine consists of *three* principal members, *generator*, *cylinder*, and *refrigerator* or *condenser*, each with sundry appendages.

The generator and working cylinder, with their appendages are nearly the same in both kinds of steam-engine, the presence of a condenser or refrigerator forming the principal and almost only distinction of the second species. By this second species the steam is returned into its first state of water, thereby effecting a saving of heat and of mechanical power; whereas, in the first form of engine, the steam, before spending nearly all its power, is discharged into the open air as useless; a process which can only be advisable in circumstances where the labour and apparatus for condensing would cost more money, and cause more inconvenience than would countervail the loss of fuel and heat and power.

As, therefore, the high-pressure non-condensing steam-engine is simpler in its action and construction than the low-pressure condensing engine, it is convenient to consider, in the first instance, its mechanism and management, and afterwards, how far it may require to be modified in order to acquire the advantage of condensation.

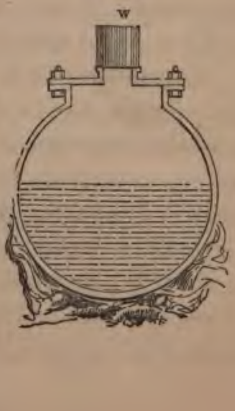
The High-Pressure Non-Condensing Steam-Engine.

The elastic force of steam is a phenomenon with which we become acquainted very early in life. We see that when water boils violently in a kettle or caldron which is closely fitted by a lid or cover, it has a tendency to raise it up or drive it off with considerable force; and that the steam, collecting in the upper part of the vessel, rushes with considerable velocity out of any crevice or pipe which communicates with the open air.

The force of the steam which is thus issuing from the spout of a kettle or crevice in the cover of a caldron is comparatively slight; and the steam which thus rises from boiling water is called low-pressure steam. But if we stop up the spout and close the cover with accuracy, so as to confine the steam within the kettle or boiler, the water will become hotter and hotter, and the steam stronger and stronger, until it will either force up the cover with violence, or altogether burst asunder the sides of the boiler. In this confined and heated state the steam acquires, from its properties, the descriptive appellation of high-pressure steam.

Engineers are in the habit of reckoning the high-pressure of steam by a very simple expedient. They place a weight such as W (fig. 38) upon a hole on the top of the boiler. This hole being square, and an inch in length and breadth, and the weight being one pound when the steam is strong enough just to blow the weight off the hole, they call that *steam of an elastic force equal to one pound on the square inch.* They then place a weight of two pounds upon this hole of a square inch,

Fig. 38.



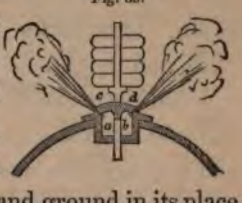
and increase the heat until the steam just blows it off, and that is called *steam of the pressure of two pounds on the square inch.* And, in like manner, when steam is confined and heated until it acquire force enough to blow weights of three, four, five, fifteen, or fifty pounds off an aperture of just a square inch in extent, that is technically called *steam of the elastic pressure of three, four, fifteen, and fifty pounds on the square inch,* over and above the pressure of the atmosphere. It is difficult to say whether there be any limit to the elastic force which steam may acquire from increased temperature and confinement: it is known to be even as powerfully elastic as gunpowder, and pressures of one thousand pounds an inch have been produced.

The pressures generally adopted for high-pressure engines are from fifteen to one hundred and twenty pounds on the inch, above that of the atmosphere. Of course, when there is a given pressure on any one inch of the surface of a boiler, there will be the same on every other inch of it; and if the aperture under the weight be any number of times greater than one inch, it will just require so much the more weight to keep it closed. The standard by which the pressure is reckoned and calculated is, however, always the square inch.

Safety-valve.—By placing a movable weight on an aperture of given size in this manner, the engineer not only ascertains the amount of the elastic force of the steam tending to burst the boiler, but also constructs a valve by which to avert the danger of such an explosion. Dr Desaguliers relates a circumstance which happened very early in the history of the steam-engine, when, for want of proper precautions of this nature, "the steam burst the boiler with a great explosion, and killed the poor man who stood near, with the pieces that flew asunder, there being otherwise no danger, by reason of the safety-valve being made to lift up and open upon occasion." Now, a given weight of lead or iron laid on a hole in the top of a boiler so as to close it, is a sufficient and common form of safety-valve; for whenever the pressure of the steam becomes sufficient to raise the weight, it escapes through the opening into the air without doing any mischief. A large weight of lead, simply placed on the opening, is a very common and simple mode of providing for the safety of the apparatus.

But this plan becomes inconvenient when the pressure and weight are great, because it is then so high as to be unsteady; and, in order to remedy the inconvenience, what is called a *valve* is used, distinct from, and in addition to, the weight, as shown in fig. 39. A valve-seat *a b*, formed of cast brass, is fixed in the aperture, and is accurately fitted by the conical valve itself *c d*, the edges of which, at *c* and *d*, are carefully turned and tapered, so as to fit the neck of *a b*, and ground in its place to be perfectly steam-tight.* A spindle protrudes down-

Fig. 39.

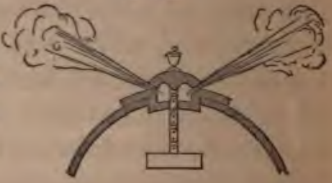


* It had been long known to the more intelligent artists that metallic surfaces which have been ground with emery powder can scarcely ever again be freed from it, and therefore they employed pumice in grinding. But it is not long since the rapid wear occasioned by emery being imbedded in the working surfaces of steam-engines, began to attract notice and to be guarded against: so that among the better informed engineers the use of emery is nearly given up, especially in grinding of valves. It has been a very common but ruinous practice to mix emery in the grease applied to new machinery, with the design of smoothing the working surfaces, whereas it rather insures that they shall never become smooth.

wards from the valve through a guide which keeps it in a straight line, and prevents it from falling on one side of the valve after having been raised. This same spindle, rising upwards, carries upon a cross-bar a series of large cylindrical weights, which may be increased or diminished in number as the case may require.

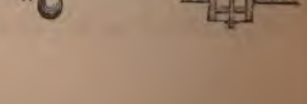
It is a practical fault of this valve that the tall erect spindle may easily become bent or injured by accident, and also that the weight upon it may too easily be handled, so as wantonly to be increased; hence, a safety valve, with an internal weight, has been contrived in the following shape. A conical valve is placed in its seat in every respect as formerly, only the spindle does not rise up but hangs down among the steam, terminating in a chain and weight.

Fig. 40.



In all these modifications the weight on the safety-valve becomes large and cumbrous when the pressure is great; and a contrivance was devised very early in the history of steam to obviate the inconvenience of this plan, under the name of the lever safety-valve. Instead of placing a great series of weights on the valve itself, a single weight is hung on the end of the longer arm of a lever so as to produce an effect proportional to its distance, and this lever being graduated, shows the amount of the effect which is thus produced. In the figure, the valve, valve-rod, and spindle are all arranged as formerly: but a lever, *g h*, rests on the top of a small hemispherical button on the

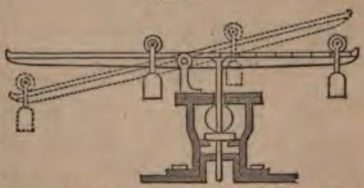
Fig. 41.



valve; and the one end *g* being a fulcrum, the weight W is suspended by a ring from any point of the lever. When, at the point 4, as in the figure, its effect on the valve is four times as great as if directly upon. The effect of the lever's own weight will, in this case, be also equivalent to a certain number of pounds on the valve, which, being properly estimated, the lever safety-valve may be used to indicate with accuracy the pressure of the steam.

Another form of valve has been proposed, as indicating still more correctly the point at which the pressure of the steam is equal to the pressure on the valve. It is a cylinder or flat valve, acted on by a lever and weight; and there are weights on opposite sides of the lever, which has also equal arms. These weights rest on light rollers so as to run down from their places and release the steam entirely, whenever its pressure reaches the prescribed limit. This is the valve of the French Academy and Franklin Institute.

Fig. 42.



Another form of valve, also cylindrical, was used by Mr Southern for his delicate experiments on high-pressure steam. The cylinder of the valve-seat used in the former figures is prolonged upwards, so as to form a vertical cylinder or tube, in which a plug of metal is exactly fitted. This plug is ground with great care, so as to move freely but steam-tight in the cylinder; and a rod from the cylinder passes up through a hole in the top, and is kept down by a lever and weight. A hole in the cylinder allows the steam to escape whenever the pressure on the valve upwards exceeds the pressure of the lever and weights in the opposite

Fig. 43.

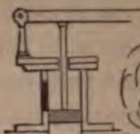
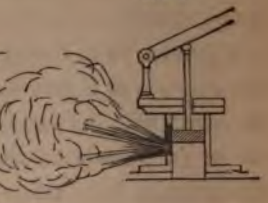


Fig. 44.



direction. The indications of this instrument are found to be very precise.

Another species of safety-valve has of late years come into use, called the spring-valve. It is of two kinds, with a lever and without it. That without the lever is represented in fig. 45. A series of bent springs, *sp sp sp sp*, &c., are placed alternately in opposite directions, in the square frame *g h k l*, and are forced down upon the valve at *n*, by a cross-bar *k h* acting at *m*—a small screw at *m* adjusting the pressure by compressing or releasing the spring.

Fig. 45.

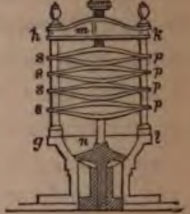
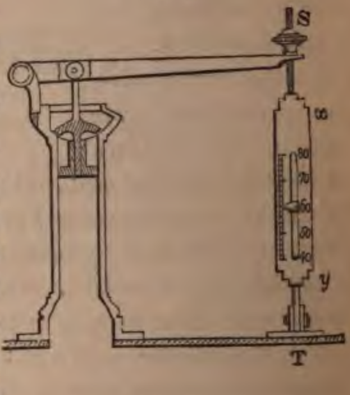


Fig. 46.



The other form of spring safety-valve interposes a lever between the safety-valve and the spring. S T, fig. 46, is what is commonly called a Salter's spring balance, the box *x y* containing a spiral spring, which is compressed in the box when the end S is drawn away from, or raised above the point S. The finger-screw S adjusts the degree of tension on the end of the lever. The last two species of safety-valve are used in locomotive steam-engines.

A totally different method of indicating the pressure of steam in a boiler, is by what is called a *mercurial gauge*, communicating with the boiler. Mercury is poured into a bent tube, one end of which springs from the boiler, and the other end is exposed to the air, so that the steam by its pressure raises the mercury in the straight limb of the tube to a height above the level proportioned to that pressure. In the figure, *a c d e* is the bent tube, communicating with the boiler at *a*, and open at the end *e*, the steam presses on the end *c* of the mercury, and raises the other extremity of the fluid to the height C. From calculating the weight of mercury, it is reckoned that, for every pound of pressure of the steam in the boiler, there is an inch of mercury raised in the tube; so that, if the space *d* C be nine inches, a pressure of nine lbs. on the square inch in the boiler is indicated. Sometimes also a small float of iron is placed on the mercury, which, carrying a slender rod with an index, points the elevation of the mercury on

Fig. 47.

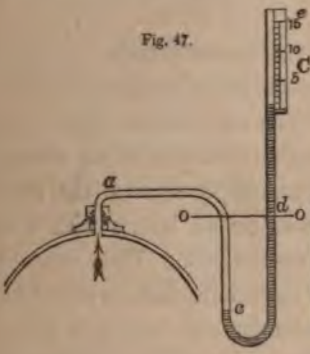
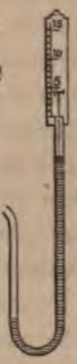


Fig. 48.



a scale above the gauge. It is evident that this instrument also acts as a safety-valve, inasmuch as the steam, when too strong, must force the mercury entirely over the top of the tube, and make its escape. A double pipe, on a larger scale, with water in it instead of mercury, would answer equally well; only the water would rise one foot and an inch for every pound of pressure of steam in the leg of the double tube, and twice that quantity if the tube were single; which would give a scale of 16½ feet in a double tube, or 33 feet in a single tube, as the column of water raised above the level by a pressure of 15 lbs. on the square inch.

It is convenient to reckon the pressure of steam in larger numbers than pounds, and the quantity that has been fixed is a weight of 15 lbs., or a stone weight, per square inch; and to this weight the name of an atmosphere of pressure has been given, simply because the common atmosphere of air presses on all bodies with a weight of nearly 15 lbs. on the square inch. Thus steam having a pressure of 15 lbs. on the square inch, is called high-pressure steam of the elastic force or strength of one atmosphere; and that having a pressure of 30 lbs. is said to have an elastic force of two atmospheres; 45 lbs. of three atmospheres, &c. Sometimes, however, a nomenclature rather different is adopted, and the common steam of boiling water, which exerts no further pressure than merely to balance the atmosphere, is called steam of one atmosphere; and in this case the elastic force which has been called one atmosphere would be considered as two. This nomenclature will be rendered evident by the following table:

High-pressure Steam of

0 lbs. on the square inch is called	0 atmos. or	1 atmos.
15	1	2
30	2	3
45	3	4
60	4	5
75	5	6
90	6	7
105	7	8
&c.	&c.	&c.

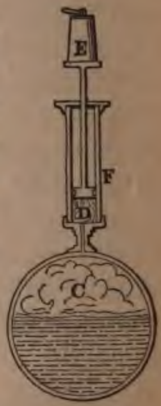
Owing to this ambiguity in these technical measures, it is always necessary to observe, and to specify, whether the pressure intended be pressure total or excess above the atmosphere of air. If, for example, four atmospheres be specified, it must be considered whether four above the pressure of the atmosphere be meant, as in the first column of the table, or four including the atmospheric air pressure, in which case the number in the second column is meant; for, in the former case, steam of 60 lbs. on the square inch is meant, and in the latter steam of only 45 lbs. above the atmosphere.

Such are some of the various methods by which the elastic force of high-pressure steam in a boiler may be estimated and shown. We have next to consider the manner in which that force may be applied to the useful purpose of forming a high-pressure steam-engine.

We have already seen how the force of steam, confined in a close boiler and heated until it acquires high pressure, acts upon every point of the surface in which it is enclosed, tending to press it asunder; and how, by sufficiently confining and heating it, weights of five, fifteen, or fifty pounds, resting on only a single square inch of surface, may be supported and upraised. To apply this force to the raising of great weights, is sometimes the object of the high-pressure steam-engine; and it has been calculated that 6 lbs. of coal, applied in heating 6 gallons of water into steam, has sufficient force to perform the most arduous labour of a man for a whole day.

One of the simplest and earliest applications of the force of high-pressure steam to raising weights, is the following given by Jacob Leupold, in his *Theatrum Machinarum Hydraulicarum*, Leipzig, 1725. We have already seen that the boiler C, fig. 49, being placed on a fire, the elastic force of the steam will raise a weight resting on an aperture. Now, if we conduct the steam in a pipe into any other vessel, such as the cylindrical tube F, in which there is a piston or movable plug D, on the top of which rests the weight E, by a metallic rod E D, connected with the piston, and passing freely through a hole in the top of the cylinder, it is manifest that when the steam becomes strong enough to overcome the pressure of the weight, it will raise up the piston to any required height. If the weight be 15 lbs., and the surface of the piston one square inch, and if the pressure of the steam exceed that of the atmosphere by more than 15 lbs., it will overcome the weight and raise it. If the surface of the piston were double the size, or two square inches, then each inch being acted on by a force of more than 15 lbs., the two inches would raise double the weight, or 30 lbs., and so on for any number of square inches. Thus if the piston were

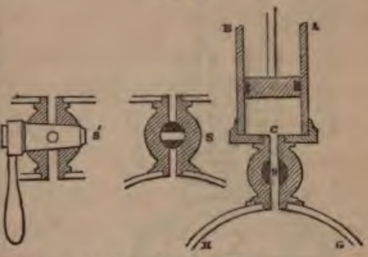
Fig. 49.



four inches in diameter, which would have a surface of about 12 square inches, on each and all of which a surplus pressure of more than 15 lbs. was sustained, there might be a total weight of 12 times 15, or 180 lbs., raised to the top of the cylinder. The boiler being removed from the fire and allowed to cool, the piston would again descend, and this operation might be repeated as often as required.

But Leupold also gives the following more convenient form of the apparatus, in which it is unnecessary to remove the fire. The boiler G H, fig. 50, having a constant fire under it, communicates with the cylinder A B C through a passage regulated by a common stopcock S, which is shown at S′ as shut by turning the handle. This stopcock remains in the position S′, or closed until the steam in the boiler is of sufficient force, and then by turning the stopcock into the position S the steam entering the cylinder pushes up the piston together with the great weight E as before. The piston will descend to the bottom, by allowing the cylinder to cool, and the weight may again be raised as at first.

Fig. 50.



But the most perfect of Leupold's machines is that in figures 51, 52. It is a true water-pumping high-pressure steam-engine; and might be efficiently used without any alteration at the present day, only the modern machines do the work with less fuel. Two pumps, T, V, for raising water are directly worked by steam, by connecting the handles G, H of these pumps with the pistons of two high-pressure cylinders, C, D, in such a manner, that when the pistons are raised by the steam the water is forced up in the pump-pipe K.

In figure 51, at A C the steam is entering the cylinder C, and pushing up the end of the lever G, so as to force the water; and in figure 52 the steam is shown entering the cylinder D, to work it. This change is effected by turning round the disc A F into the position which reverses the passages. Thus, while the steam is entering the cylinder C, fig. 51, through A C, the steam from the cylinder D is escaping through E F into the open air; and in fig. 52 the steam is passing into the cylinder D through A E, and out of the cylinder C through C F. The action of this *four-way stopcock* is very simple and beautiful, and deserves to be carefully studied. By con-

Fig. 51.

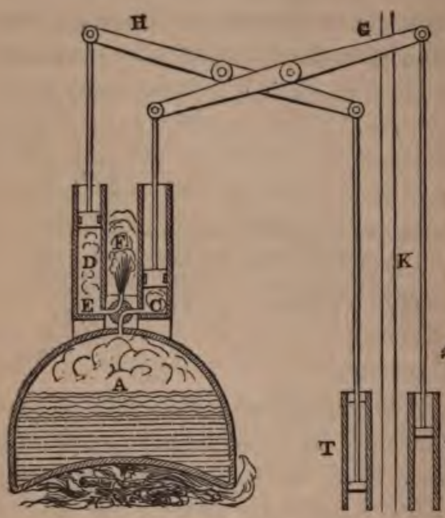
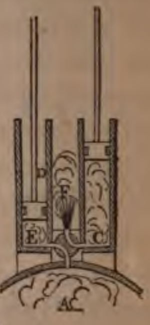


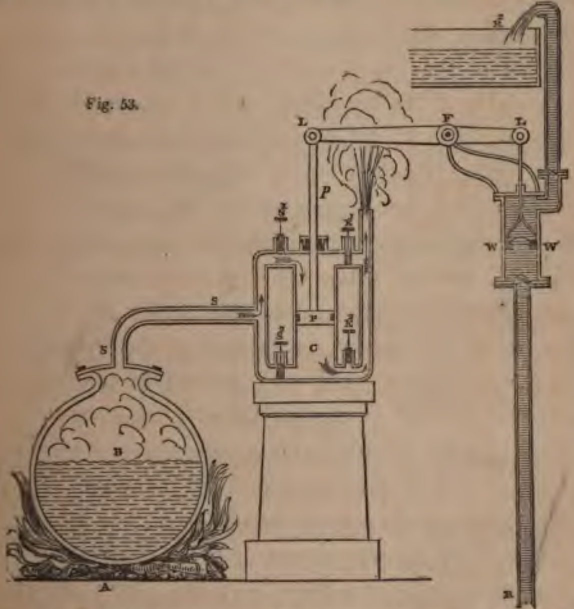
Fig. 52.



tinually turning it in one direction, communications are simultaneously effected between the boiler and each of the cylinders alternately, and between each cylinder and the open air. We shall afterwards revert to this mechanism.

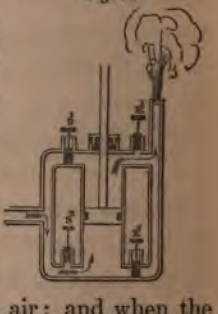
The modern steam-engine of high pressure is in many respects analogous to the machine of Leupold. It will be readily understood from the following illustrations. The engine is called double acting, because the steam not only enters the cylinder below the piston to raise it, but also above the piston forcibly to depress it. The boiler B is on the left of the figure; the pump, for raising water from the reservoir R to the reservoir R², is on the right; and the cylinder C in the middle. From the boiler a *steam-pipe* S S proceeds to the upper and lower parts of the cy-

Fig. 53.



linder C; and on the right hand side of the cylinder there are two *eduction-valves* E^1 and E^2 to allow the steam to pass into the upright eduction-pipe which discharges it into the open air, after it has performed its duty, but having still an atmosphere of its force unspent. The piston P is accurately fitted into the cylinder, so as to be air and steam tight, and the piston-rod p is made to carry with it the end of the lever L F L, and work the pump W W. Perhaps the only difficulty in understanding the mechanism of the double-acting steam-engine, lies in the construction and operation of the valves. S^1, S^2, E^1, E^2 are four plugs, each capable of exactly filling up the passage in which it is placed, like S^2, E^1, or of being withdrawn from it, like S^1, E^2. Therefore it is evident that in figure 53 the steam has free access under the upper valve S^1, into the cylinder above the piston, so as to press it down. In fig. 54, the case is shown reversed: the valve S^1 is shut down, allowing steam to pass only under S^2, the lower valve, so as to enter at the bottom of the cylinder and force the piston up. The arrangement of the eduction-valves E^1 and E^2 is also to be observed. In fig. 53, where S^1 is open and S^2 shut, E^2 is also open, and E^1 shut; so that, while steam enters freely under S^1 on the upper side of the piston, pressing it down, there is a free passage for escape of steam from the under side of the piston, by the bottom passage under the valve E^2, and then up the eduction-pipe to the open air; and when the whole is reversed, as in fig. 54, the steam valve S^2 at the bottom being opened for ingress of steam below the piston, and E^1 being also raised, gives free egress to what

Fig. 54.



was formerly admitted above, so that it may now pass under E^1 and up the eduction-pipe into the open air. Thus, then, by opening and shutting alternately each of the two pairs of valves, first the under steam-valve and upper eduction-valve, and then the upper steam-valve and under eduction valve, so as first to allow steam to enter above and escape below, and then to get in below and out above, the one pair being always shut when the other is open, the whole effect is accomplished.

It is an object of great importance to the precision of a machine's operation, that it should be self-acting or automatic; that is to say, that it should not require for its successful action the continual assistance of an attendant. In the machine just described, the valves are supposed to be opened and shut by the attendant. With the following simple mechanism the valves are opened and shut by the machine itself:—

The two valves S^1 and S^2 are connected together by a straight rod, and the two eduction-valves E^1, E^2 by another straight rod; these valve-rods are made to rest on opposite ends of a lever *l l*, which turns on a centre O. By this simple arrangement it is brought about that the pair of valves S^1, S^2 being depressed, as in fig. 55, the other pair E^1, E^2 are raised; but when, as in fig. 56, S^1, S^2 are raised, E^1 and E^2 are depressed, while at the intermediate position both are situated similarly to each other. In the next place it is to be noticed, that the rod E^1 E^2 is prolonged to T upwards, and that it carries two projections fixed to it at M and T. These projections are struck by the lever LL as it rises and falls. When, in fig. 55, the lever is making its downward stroke, it comes on the plug M; and pushes it down, first into the middle position, and then into the position of fig. 56. The steam then entering below, raises up the piston to the top of the cylinder, and with it raises also the lever, which striking on the upper plug T, carries it upwards, raising the eduction-valves E^1, E^2, and allowing the opposite valves S^1, S^2 to descend into the position of fig. 55, as at first. This operation being repeated, so that at the end of each upward and downward stroke, the descent and ascent of the piston and lever prepare the valves for producing the inverse effect, and giving the next succeeding stroke, the machine becomes independent and automatic. It is not long since these simple valves were first introduced in the steam-engine.

Fig. 55.

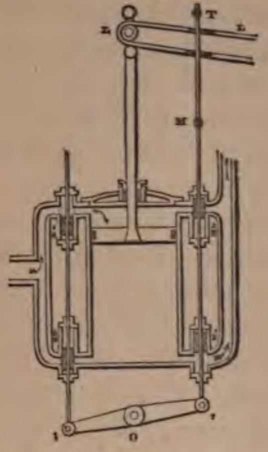
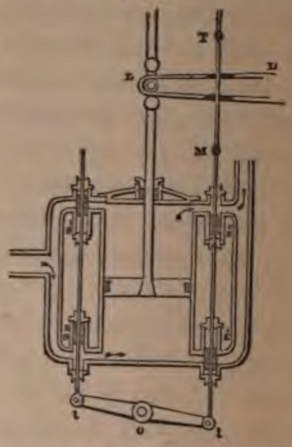


Fig. 56.



Considerable ingenuity has been exerted with the view of forming all these communications by means of two passages, instead of four. The following diagrams are designed to explain the manner in which this has been effected, by a four-way cock, similar to that introduced by Leupold into his high-pressure engine. For this purpose the steam-pipe S, the eduction-pipe E, and the pipes of the upper and lower ends of the cylinder, are all brought to the circumference of a single circle, so as to form a St George's cross, as in fig. 57. A metallic circular disc O P O B, with two curved channels communicating at successive quadrants of a circle, as shown in fig. 58, is inserted in this circle, so as to fit it exactly, and to be moved round by a handle H. In fig. 59, this valve is represented in the working position, a communication being formed from S to A, and the other from B to E; and, in fig. 60, the handle being pushed down, a communication is made betwixt S and B, and between A and E. The means of effecting this is given in fig. 61. A vertical rod T T^2 being suspended from the great lever, with two plugs T, T^2, by which the handle H of the valve is raised; in that position the steam enters at S, and passes up the superior passage into the top of the cylinder, forcing the piston

Fig. 57.

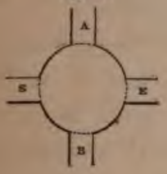


Fig. 58.

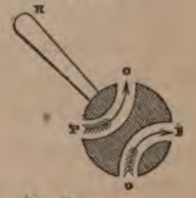


Fig. 59.

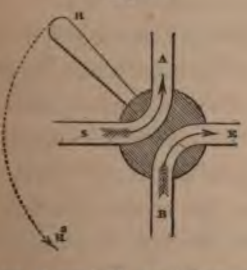
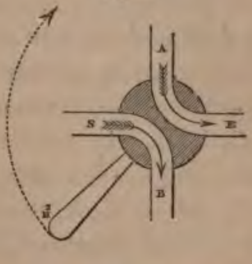


Fig. 60.



Another form is that called the long slide or long D-valve, the invention of Mr Murdoch, which gives the advantage of shutting off the steam, close to its ingress into the cylinder; and so saving what in the common short D-slide is lost in the passages from A and B to the ends of the cylinder. It is formed thus. The valve-chest extends along the side of the cylinder. It is shown in fig. 67, without the valve. In figure 68 the long D-slide valve is shown separately. It is a sort of pipe extending along the whole length of the cylinder. Towards the ends, this pipe is almost semicircular, with two narrow flat plates capable of covering the openings or ports of the cylinder. This pipe is left open, and perfectly clear from the one end to the other, so that the steam may traverse it freely lengthwise. The steam-pipe is represented as entering the valve-chest from below at S, and the eduction-pipe in the middle as at E. In this valve-chest are placed packing-boxes, as they are called, immediately opposite the ports of the cylinder. They contain soft elastic hemp, soaked in oily matter, the object of which is to press against the truly cylindrical and polished outside of the slide-valve when in its place, and make steam-tight partitions in the valve-chest, to prevent communication between the middle and the two ends.

Fig. 67.

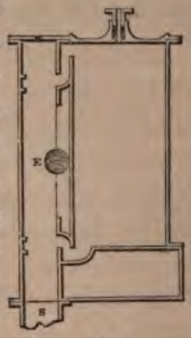
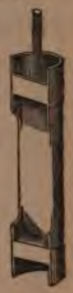


Fig. 68.



In the figures 69 and 70, the valve is shown in the working position. In figure 70, the steam from S rises up along the centre of the slide, and enters the upper port A, while the steam in the under part of the cylinder has free egress through B to the eduction-pipe E. In figure 69, the steam has free access to the lower port B, while the steam already above the piston has free egress through the upper port A to the eduction-pipe E. In this species of slide, there is scarcely any loss of steam in the passages, as it is cut off close to the cylinder.

Fig. 69.

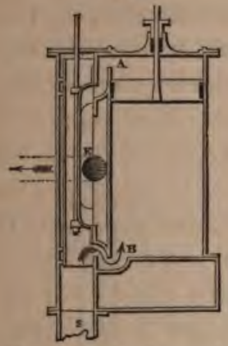


Fig. 70.

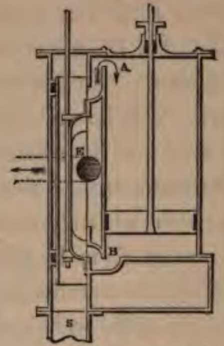


Fig. 71.

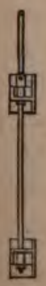


Fig. 72.

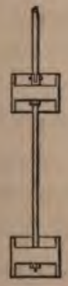
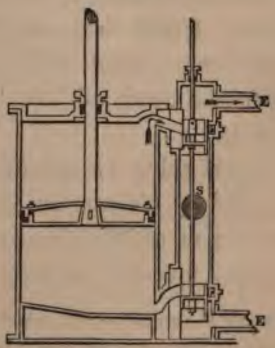
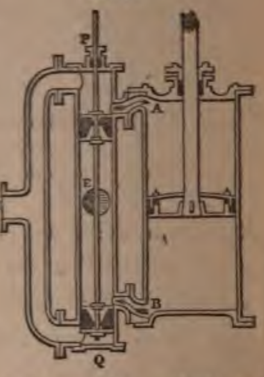


Fig. 73.



Instead of the long D-slide, which is very heavy on a large scale, two short slides, similar to its two ends, and connected together by bars, have been used in the following form. Fig. 71 is a section of the slide, fig. 72, a face view; and fig. 73, a section of the cylinder with the valves in their places. In this case, however, there are two eduction-pipes E, E instead of one, as formerly, and the steam-pipe S enters between the valves.

Fig. 74.



A cylindrical slide-valve of the following form is used in a considerable number of engines, and works well in those cases which we have had an opportunity of examining. The valve-chest is an upright cylindrical pipe P Q, the inside of which is bored truly cylindrical, and is exactly fitted by two metallic cylindrical plugs, which are ground so smooth in their places as to be steam-tight. It will be apparent from the figure that these two plugs being raised and depressed by the valve-rod which connects them, will effect the same purpose as the former valve.

The conical valve is a species introduced by Mr Watt, and improved by his assistant Mr Murdoch, from whom the steam-engine of Watt has received many valuable appendages, and much of its practical perfection.* It has been applied in two forms. Mr Watt's own form, the earlier one, is given in the following figures. For a single engine four valves are required. One of them is represented separately in figures 75, 76, which are vertical sections through the valve, at right angles to each other. The valve is shown open in fig. 75, and shut in 76. S is the entrance of the steam, A the port, V the conical valve, and N the seat or nozzle which it covers. On a cursory glance, it is evident that when the conical cover V of the aperture N is up, as in the first diagram, the steam has free entrance; and when it is closed, the steam will merely press the valve down into its seat, without obtaining an escape from the nozzle. The manner in which this is effected for all the passages, is shown in the following perspective diagram, fig. 77: *a d d* is the steam-pipe from the boiler; *g g* the eduction-pipe; *b* the upper steam-valve; *e* the lower steam-valve; *h* the upper exhausting valve; *i* the lower exhausting valve; *c* the upper port of the cylinder; *f* the lower port. The seats of the exhausting valves *h* and *i* are inverted; so that these valves open when

---

* This, which is also called the spindle-valve, or button-valve, answers well for many purposes when due care is taken to have the spindle steadily guided at both ends, to prevent the valve from rubbing on the side of the seat or aperture while shutting. Frequently, however, when used as a safe-

Fig. 75.

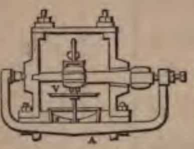
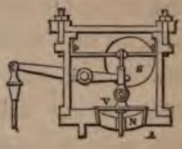


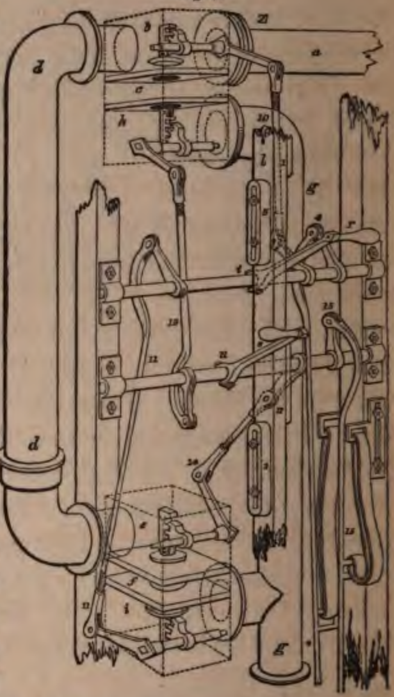
Fig. 76.



ty-valve (see fig. 39,) it has no guide of any sort for the upper end of the spindle. Instead of this a load of weights is put on the top. These cause it to lean over to one side, and of course in shutting it wears away at that side, which soon makes it leak. In a very similar, but still more loose and degraded state, it is much used by plumbers. Being loaded on the top, it leans to a side and rubs hard in shutting. The consequence is that it leaks almost from the first, and daily gets worse. The very frequent need of renewing such wretched valves in water cisterns, &c., is a serious tax on the owners.

drawn downwards, while the steam-valves open when drawn upwards. Each valve has a toothed rack attached to it, which is acted on by a toothed sector, fixed on an axis, whose end passes through the valve-box and carries an arm or handle by which it is moved as follows:—the arm or handle of the upper steam-valve is connected by the rod 10 with an arm fixed on the axis *t*, and the arm on the axis of the lower exhausting valve is also connected by the rod 11 with a similar arm fixed on the same axis *t*. The arms of the lower steam-valves and upper exhausting valves are in the same manner connected with arms on the axis *u*, by means of the rods 13, 14. These axes *t*, *u*, carry each a handle *tr*, *us*; and on these the plugs or chocks 1, 2, 3, 12, of the plug-rod *l* 12, act. When the plug-rod is descending, its chock 1 comes in contact with the handle *tr* of the axis *t*, and depressing it, turns round the axis *t*, so as to shut the upper steam-valve and the lower exhausting valve; and at the same instant its chock 3 comes in contact with the

Fig. 77.



handle *us* of the lower axis *u*, and depressing it, opens the lower steam-valve and the upper exhausting valve. In the upward motion of the plug-tree, the positions of the handles are reversed by the chocks 12, 2. The axis *t* carries a short lever 4, to the end of which there is a weight hung through the rod 4 4. When the valves connected with the axis *t* are opened, this weight keeps them open; but is prevented from opening them too far by the strap attached to the rod, as seen in the figure. The lower axis *u* has a similar apparatus, 15, 15, for the same purpose. It remains to notice how the exhausting valves are prevented from being opened by the pressure of the steam. The rods which connect the arms on the axes of the valves with the arms on the axes *t*, *u*, it will be observed, are bent at one extremity in such a manner as that when the valves are shut, the connecting rods and the arms on the axes *t* and *u* fall into the same straight line, as is seen in the case of the upper exhausting valve in the figure. In this condition the arms of the axes *t* and *u* cannot act as levers in turning these axes round, and the valves are thus effectually locked until released by the action of the chocks upon the handles *r*, *s*.

Mr Murdoch's conical valve is represented in the next figures: fig. 78 a side view, and fig. 79 a front view.

a d d are steam-pipes, and *g g g* eduction-pipes as formerly; *c* being the upper port of the cylinder, and *f* the bottom port; *b* and *e* the top and bottom steam-valves, *h* and *i* the top and bottom eduction-valves. The steam-valves *b* and *e* are raised or lowered by hollow rods or tubes, through which the spindles or rods of the eduction-valves *h i* work freely without interference. A rod 10 joins the short levers 19, 20 of the valves *b*, *e*, together, and another rod 13 joins the levers of the valves 18 and 21 together; so that by inserting into sockets, formed on the ends of the levers 20, 21, the bars *r*, *s*, shown by dotted lines, and by using them as lever handles, the upper steam and lower eduction-valves are opened simultaneously by the handle *r*, and by the other lever *s* the lower steam and upper eduction-valves are opened also simultaneously and alternately with the former. The rods 10 and 13 are connected by the rods 11 and 12, with an apparatus of levers and weights, acting through an axis at 22, by which the valves are retained in their seats.

Fig. 78.

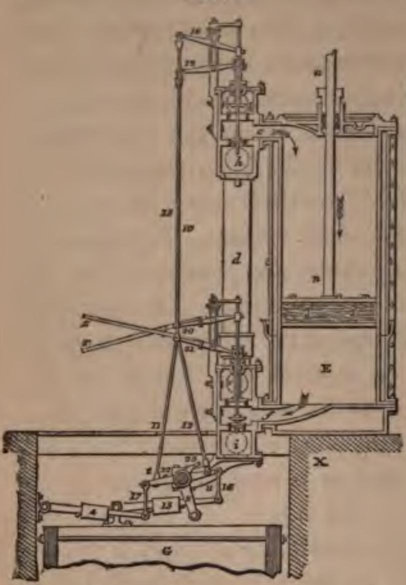
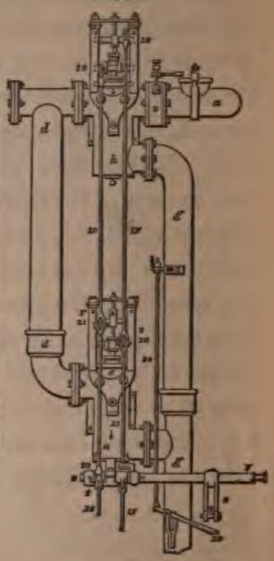


Fig. 79.



The last valve which we shall describe is the crown-valve, or equilibrium valve, which is in use on the Cornish engine, and has also been introduced into rotative engines.

Its value consists in effecting a large opening, and requiring little force to work it, while large valves of the common sort are heavy, or are so much pressed in one direction by the steam as to require great force to work them. The crown-valve is so named from its resemblance to a diadem. Conceive a chamber, fig. 80, out of which an aperture A leads into the cylinder, and into which a pipe S brings steam. The aperture A is surrounded by an upright ring or collar rising a few inches into the chamber, which ring is on all sides perforated by slits of considerable size, but closed at the top. Figure 81 represents the crown or cover of this valve, which is also a ring attached to a steel rod or spindle, by which it is raised or depressed. All round at top and bottom, the collar in the chamber and the crown-valve are ground so as accurately to fit each other. Fig. 82 shows the valve on its seat and closed on all sides, so that no steam can find admittance; and fig. 83 represents it open or raised up from its seat, with steam entering freely on every side.

Fig. 80.

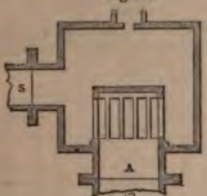


Fig. 81.

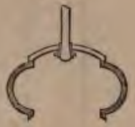


Fig. 82.

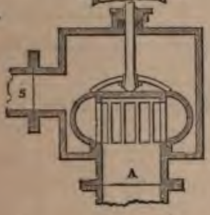


Fig. 83.

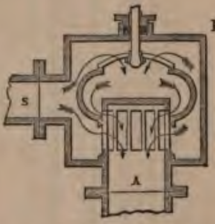


Fig. 84.

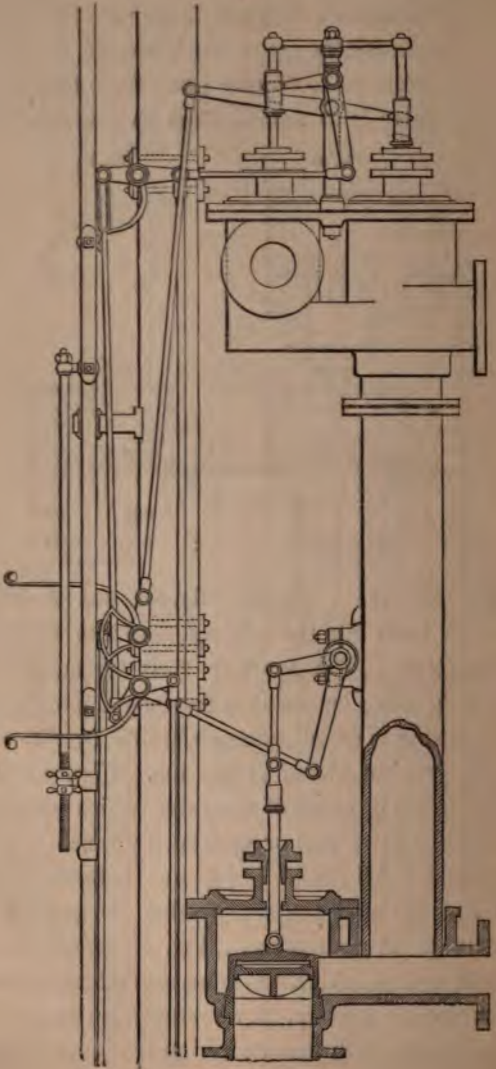
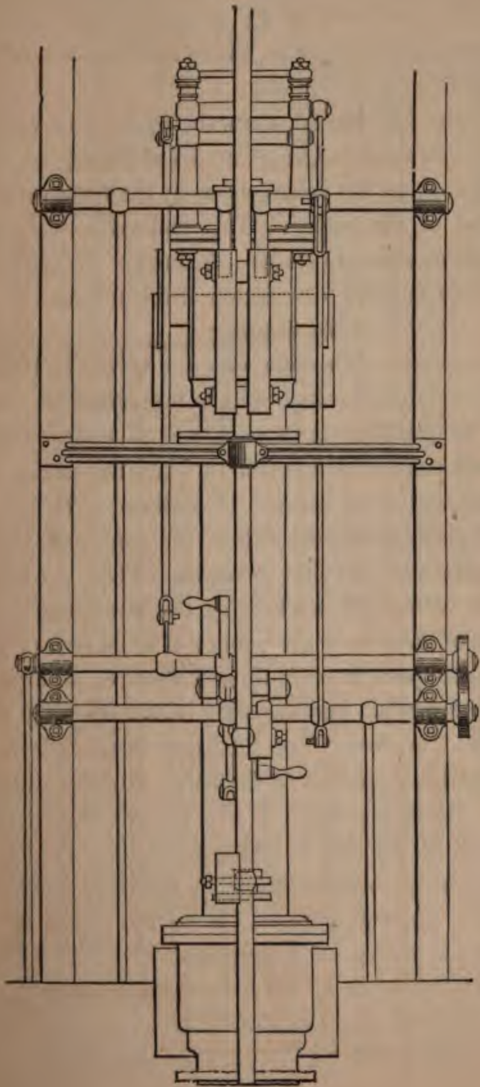


Fig. 85.

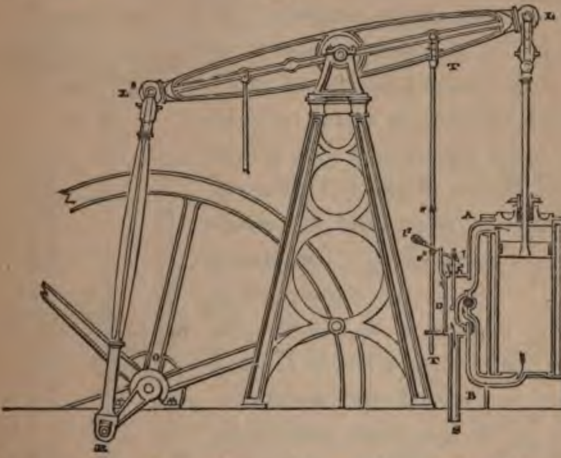


These valves are arranged similarly to the common conical valves, and work in the same way, four of them being used in a single engine, instead of four conical valves, as in fig. 77.

The large figs. 84, 85, show the equilibrium valves and valve-gear as employed in a Cornish steam-engine, with the gear for working the valves either by the hand or with the pump-rod of the engine. This method is very perfect and deserves attentive study. Although we cannot here enter into a detailed description of the mechanism, it will be understood from the drawing.

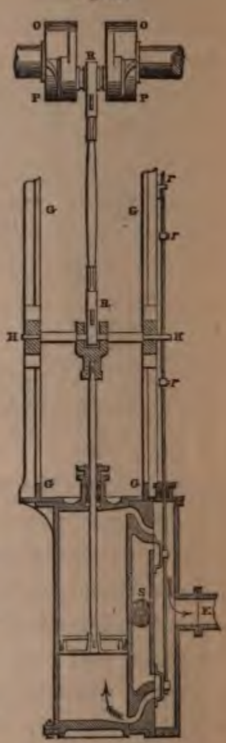
In immediate connection with the valves and passages of a steam-engine, which admit the steam on alternate sides of the piston to do its work, and afterwards discharge it, we may consider the means by which the engine is rendered automatic, or capable of performing its labour, in the most perfect manner, without the continual assistance of a man to open and shut its valves. There are two ways in which valves are worked by the steam-engine itself. The first of these is by the agency of some part of the engine that happens to move up and down, or performs a reciprocating motion, and the other is by the agency of some part which revolves. The following is a simple method, which has been applied to the short D-slide, already described. In figure 86, A B P is the cylinder, P the piston, acting on the end L, of the great lever L L^2, raising and depressing it alternately, while the other end L^2, united by the connecting rod L^2 R to the crank of the fly wheel, turns it round. The manner in which the steam-valves are moved, is by the long vertical bar or plug-rod T T, suspended from the lever L L^2, so as to move up and down with it. This bar T T carries two projecting plugs of wood s s^2 upon it, which strike alternately up and down upon the handle l l^2 at the bottom and top of the stroke, and so produce the reciprocating motion of the slide-valve D; and by admitting the steam on alternate sides of the piston, and discharging it at the opposite ports, produce the continuous motion of the engine. In the figure, the steam is supposed to be forcing down the piston; but when the piston gets near the bottom, the plug s will have come in contact with the valve-rod l l^2, and will have forced it and the slide-valve D into the opposite position, and so permitted the steam, formerly above the piston, to pass into the open air, while the steam on the other side presses up the piston, so as to bring the plug s^2 in contact with the lever, pressing it up, and the valve D down into its first position, and so on alternately.

Fig. 86.



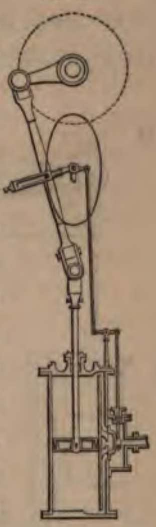
This method of moving the valves by a plug-frame, rising and falling with the strokes of the piston, was first introduced by Beighton (with very different valves) about the year 1718. It has been principally adopted for pumping engines that have no revolving motion. We have, however, seen it used with advantage even in marine engines. It is noisy, as the sudden strokes of the plugs produce an instant jerk; but it is effective, in so far as it at once opens the ports to their fullest extent, and so allows full effect to the entering steam, and full clearance to that escaping. The form in which we have seen it adopted in marine engines is as follows. In fig. 87 the ends of a bar H H fixed across the top of the piston-rod, move along the guide posts G G, and thus form a sliding parallel motion. R R is the connecting rod, and O P O P the crank. The valve-rod *r r* is extended upwards as far as the piston-rod works, and two plugs *r r* are so placed by adjusting screws, as to admit of the rod being raised and depressed at the proper moment by a projecting part of the cross bar H, at the end of each upward and downward stroke.

Fig. 87.



A very different method of working the valves has been invented by Mr Melling, superintendent of locomotives on the Liverpool and Manchester railway. It derives the motion of the valves from the connecting rod, one end of which moves round in the circle of the crank, while any point between the ends performs a sort of elliptic motion. Thus Mr Melling makes a round pin to project from near the middle of the connecting rod, fig. 88, and the curve described by this pin manifestly resembles, although it is by no means a correct ellipse. It is an oval having its lower end more acute than the upper and deviating the more from a true ellipse as the connecting rod is shorter. Since the pin does not describe a circle, it is made to act in a slit in an arm which proceeds from a fixed axis in the centre of the oval. This arm the pin carries round, together with a small crank on the same axis; and the valve rod is moved by this crank just as by the eccentric described a little farther on. But this scheme is so much more complex than the eccentric, that it can scarcely have less friction; and it unfortunately causes a much greater proportion of the motion of the valves to occur while the piston is in the middle of its stroke, than the eccentric does.

Fig. 88.



One of the most common of the many applications of the steam-engine is to turn round an axle and wheel; and in the second system of valve apparatus, by which the steam-engine is rendered automatic, the steam-valves are worked by the revolving of one of the shafts or wheels. Of the various methods in which this has been done, the following are some examples.

On the axis *o* of the crank (at the bottom of the right ide of fig. 89,) which is turned round by the rod LR dur-ig each alternate ascent and descent of the piston, is placed a cam or projection. A square frame $s^1\ s^2\ s^3\ s^4$ encloses this cam. As the axis turns round, the cam comes into such positions as to bear upon the sides $s^1\ s^2$ and $s^3\ s^4$ of the frame successively, and so pushes the frame towards the right and left alternately. *s e v* is a bell crank which

Fig. 89.

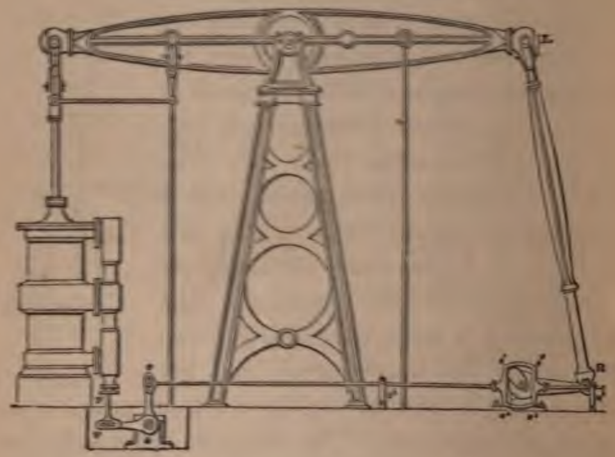


Fig. 90.

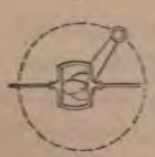


Fig. 91.

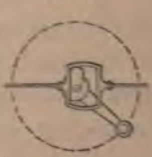
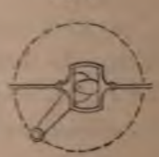


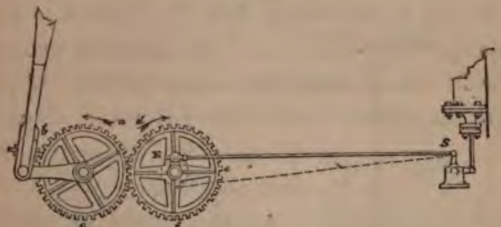
Fig. 92.



the horizontal rod ss^1 attached to the frame moves on its centre *e*, and so shifts the point *v* and the valve-rod *v v* up and down alternately together with the valves. The different positions into which the frame is forced by the cam are sketched in figs. 90, 91, 92.

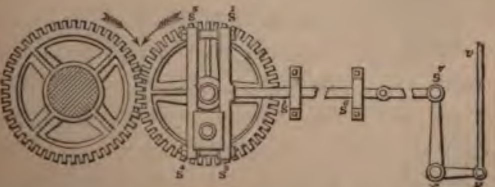
Another form in which this motion has been given, is by connecting the large axle of the crank with a smaller axle, by toothed wheels. The principal or crank axis, fig. 93, carries round a wheel *a b c* which drives the equal wheel *d e f*. There is a projecting pin E out of the centre, to which the crank S is connected by the rod E S so as to raise and depress the valve-rod. It is manifest that, during the revolution of the wheels *a b c* and *d e f*, the point E will be carried round a circle, and communicate alternate motion to the rod E S, equal in extent to the diameter of that circle. This circle must, therefore, be chosen of a diameter equal to the required motion or throw of the steam-valves attached to the cylinder.

Fig. 93.



This motion has been modified into a very excellent and durable arrangement in the following form.

Fig. 94.



Here the toothed wheels are as in the former figure, and the eccentric pin or crank-pin is carried round by the inner one. On the crank-pin is a square brass nut or collar, made to fit exactly a space left between two parallel bars S^1 S^2 and S^3 S^4 that are kept in their places by nuts and screws at their extremities, and capable of adjustment. These bars are connected with the horizontal bar S^5 S^6, which works steadily through the collars S^5 and S^6, and from its end a connecting link S^6 S^7 passes to work the crank and valve-rod S *e v*. This apparatus we have seen work well without repair for a long period. It was executed by the Messrs Carmichael of Dundee. Figs. 95, 96, 97, show the apparatus in three other positions.

Fig. 95.

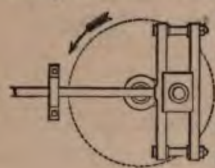


Fig. 96.

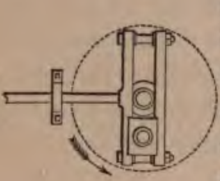
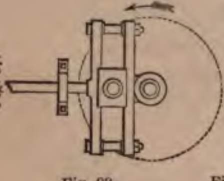


Fig. 97.



Another mode of moving the valves is by a projection in the great axis of the engine itself. A rigid circular hoop S encloses the axle as in figs. 98, 99, 100, 101. It is evident that if the projection E, reckoned from the centre of the axle, did not exceed the radius of the hoop, the axle would revolve without moving the hoop; but if, on the contrary, the axle and its projection be equal to the diameter of the hoop, as in figs. 98, 99, 100, 101, it is apparent that the projection or cam,

Fig. 98.

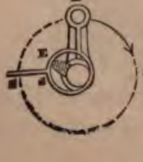


Fig. 99.

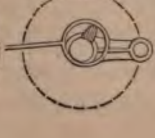


Fig. 100.

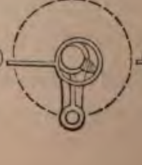
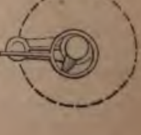


Fig. 101.



in passing round, must push the hoop in alternate directions.

Fig. 102.

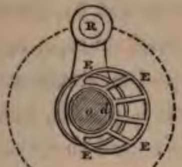


Fig. 103.

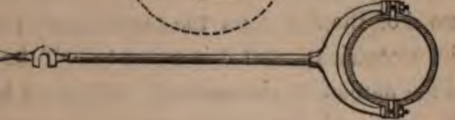


Fig. 104.

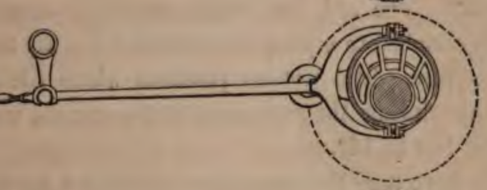


Fig. 105.

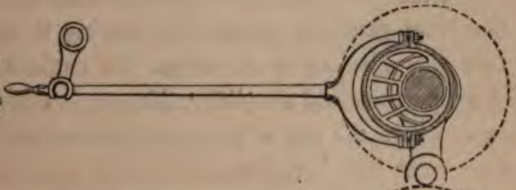


Fig. 106.

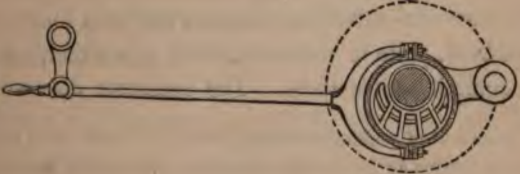
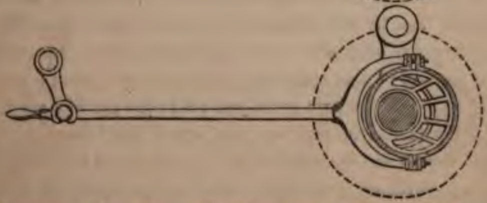


Fig. 107.



But that modification of this principle, which is in by far the most general use, is in the form called "the eccentric," which is a circular disc, or ring of metal, placed upon the shaft or axis, turned by the crank. In fig. 102, O is the centre of the shaft or axis, to which revolution is given by the crank R of the steam-engine. On this axis the circular disc E E E is placed, but eccentric to it, so that its centre *d* moves round the axis. The distance of the centre *d* of the disc from the centre O of the axis, is called the eccentricity, and it is equal to half the throw or range of the motion of the valves to be moved by the eccentric.* The rod, fig. 103, is called the eccentric rod, and is attached to a hoop or circle that exactly fits the eccentric disc. The various positions which the eccentric will take during the revolution of the engine, is shown in figures 104 to 107.

We have used the common eccentric in a much simpler form than that generally adopted, by placing it immediately over the valve which it moves. In engines which require compactness and simplicity, this way is useful, and is valuable where the axis of rotation is immediately over the valves, as in figs. 108, 109.

In these the valve-rod branches out into four portions; a flat brass plate is inserted at their separation, another at the summit unites them. The eccentric disc works between the side forks of the rod, and bears against its top and bottom plates, as seen in fig. 108. The width of the other forks of the rod is made equal to the diameter of the axle, which thus prevents the rod from deviating from the vertical position, as seen in fig. 109; a handle is added to work by hand, and the reversing process is performed as usual.

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* A method of working the steam-valves, by a much more obvious and simple substitute for the eccentric than that of Mr Melling already described, might be had by virtually forming a small crank upon the great one. Thus if upon the outer end of the large crank-pin an arm were fixed parallel to the arm of that crank and carried inward ; then a projecting pin properly placed on this arm could just act as the pin of a small crank having the same axis as the great one, and which could move the valve rod in the same way as the eccentric does, but with much less friction. For an eccentric is obviously just a short crank, with a crank-pin so enormously thick as to occasion great friction.

Fig. 108.

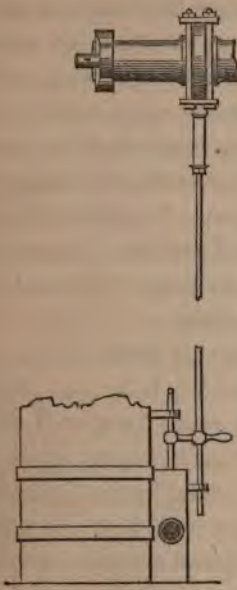
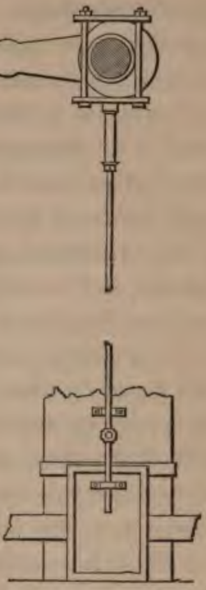


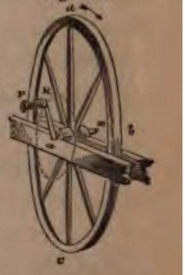
Fig. 109.



The Crank.—One of the most important appendages of the steam-engine is the crank, by means of which the force of steam, although at first producing motion only upwards and downwards in the straight line of the axis of the cylinder, is nevertheless rendered capable of exerting that force equally well in a circular direction. When the steam-engine is only employed for some such purpose as pumping up water, no crank is necessary, but as some of the most usual and valuable applications of the steam-engine are those where it turns wheels of mills, of cotton machinery, of steam-vessels, or locomotive engines, the crank, by which this is accomplished in an admirable and simple manner, which has superseded every other plan of transmission, is entitled to very minute consideration.

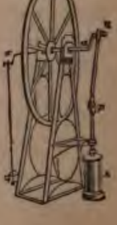
A crank is an elementary machine which has been used from the earliest times for converting a revolving into a rectilineal motion, or the reverse. It is figured in descriptions of the old machines of the Egyptians, Chinese, Greeks, and Romans, and in water machinery it has been in common use from the time of Ctesebius.

Fig. 110.



A crank is merely a handle to a wheel, by which it may be turned round. In fig. 110, let *a x* be an axis of a wheel *b c d*, and *a* R P the usual bent (or crooked) handle, by which it is turned round by the man, whose arm first pushes it from him, and then draws it towards him, and so continually turns the wheel round, then the part *a* R radiating from the centre, is called the crank, the axis *a x* is called the crank-axle, and the straight part PR is called the crank-pin.

Fig. 111.



Now imagine, instead of a man's arm, a rigid metallic connecting-rod, and instead of the strength of his body, conceive the force of steam to be applied, through a cylinder, piston, and piston-rod, to the crank by means of the connecting rod, and the steam will turn round the wheel by means of the crank, axle, and pin, as in figure 111. A being the cylinder, *p* the piston-rod, *p* R the connecting rod, R the crank, and *a x* the axis.

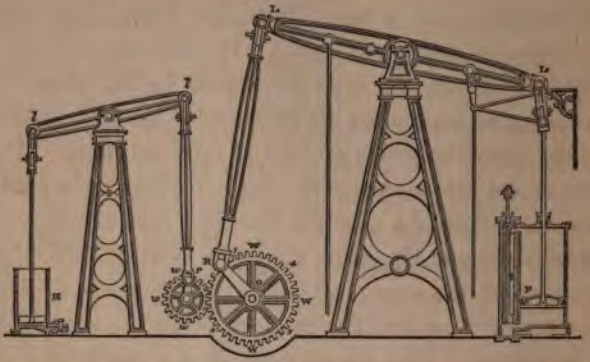
On examining, in detail, the action of the crank, it is to be observed that the force exerted by the steam is neither constant in direction nor in action. If the steam be admitted first below the piston, it forces it to the top of the cylinder; it is then cut off preparatory to its being admitted above the piston; and in the interval it has no motive action. When admitted above the piston, it forces it to the bottom of the cylinder; and again there is a cessation in its action during the change in the position of the valve. Now it is evident that this recurring cessation of action between the alternating impulses would interrupt the continuous revolution in the wheel, but for the power of the wheel itself to continue the motion, by what is termed the momentum of its mass. When the steam, during a stroke of the machine, is acting most powerfully on the piston, part of its power is spent in accelerating the wheel; and when, at the end of the stroke, it ceases for a time to act, the wheel gives out the power which it had gained, and continues its motion until the next stroke gives it a fresh accession of power. A wheel of this kind, when attached to an axle for equalizing motion, is termed a fly-wheel; and to obtain the full benefit of its equalizing power, it is made of large diameter, that its rim may move rapidly, and it is made of great weight, being formed either of lead or iron, that it may acquire momentum to render the motion as uniform as possible.

Still, however, it must be remembered, that the equalization of the motion produced by the fly-wheel is partial, not perfect. Matter only takes up or gives out force when it changes from one velocity to another. If, therefore, the fly-wheel take up into itself the accession of force of the steam at one part of the stroke, it does so by slightly accelerating its motion; and if it give out force during the cessation of the stroke, it is by slightly reducing its own velocity in so doing. The approximation to perfect uniformity in the motion of the steam-engine, will be proportioned to the mass of matter in the rim of the wheel and to the square of the wheel's velocity. Although, therefore, the fly-wheel improves the action of the crank, so as to adapt it to all ordinary purposes, still the effect is not so equable as the power of a water-wheel, where *extreme* delicacy is required. In all ordinary cases, it is sufficiently uniform.

The following substitute for a fly-wheel was suggested and constructed by Mr Buckle of Soho, for Mr Lucy of Birmingham, and is an admirable and elegant substitute or auxiliary; so as to be, for even the most delicate operations, practically perfect. Mr Lucy had constructed at Birmingham, a flour mill driven by steam; and it had been his object to obtain perfection without any limitation of expense. He had got one of Boulton and Watt's best steam-engines, and yet he found that his mill neither produced such perfect flour nor moved so smoothly as mills driven by water. On the contrary, it was found that the inequality of the motion produced a larger quantity of coarse than of fine flour, at a mercantile loss to the owner: and it was likewise found that the irregular propulsion from behind interfering with the uniform motion, towards which the millstones tended by their own momentum, produced a changing reciprocation along the whole line of toothed gearing, which was most injurious, and rapidly destructive to the toothed wheels. The usual plan of increasing the weight of the fly-wheel was resorted to without success; and Mr Lucy applied to Mr Buckle to propose a remedy for the evil. This remedy Mr Buckle found in the contrivance of a pneumatic pump. In the mint at Soho, a pneumatic pump had been introduced by Mr Watt, for producing a reaction, on the principle of the experiments of Otto Guericke, which we have already described. The force of the steam-engine was made to draw up a piston from the bottom of a cylinder, leaving a vacuum below it. Into this vacuum the piston was again carried down, after the action of the steam had ceased, by the whole force of the atmosphere, amounting to about 15 lbs. on every inch of its surface. Thus the atmosphere was rendered a reservoir of power, the power being first of all taken up by forming the vacuum, and again given out by the atmosphere pressing the piston down into the vacuum.

The following is the arrangement by which Mr Buckle accomplished his object. P, fig. 112, being the usual piston and cylinder of the steam-engine, L L the usual beam or lever, L R the connecting rod, R O the crank, and R W W W a toothed wheel carried round by the crank, as usual in the steam-engine. To this is added a smaller wheel *r w w*, having only half as many teeth as the larger, so that during one turn of the small wheel, the large one performs half a revolution; *l l* is a second lever attached by a rod to a crank *r*, and by another rod *l* H it lifts a piston from the bottom to the top of an open pump H, leaving a vacuum beneath. When the piston is at the botom of the pump, the crank R is near the point 1 in the figure. While the crank passes down from 1 to 2, it is raising the piston in the pump against the pressure of the atmosphere, the steam then exerting its greatest force; but when the large crank reaches point 2, the small crank *r* is at the bottom of its circuit, the piston in the pump is at the top; and now the pressure of the atmosphere carries the piston down into H, turning the little wheel *r w w* along with it, and propelling the large wheel and crank from 2 to 3, through that part of the stroke where there is a cessation of the action of the steam: then again from 3 upward to 4, the excess of the power of the steam is employed in raising the pump piston; while from 4 to 1 that piston carried down by atmospheric pressure, brings round the mechanism again to the point 1.*

Fig. 112.



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* This, although in some respects an ingenious and efficient scheme, is executed in a form which is very unnecessarily complicated and expensive. The force which urges the piston down into the pump, consists of so many pounds of atmospheric pressure together with the weight of the piston itself, that a mere weight equivalent to the required force, and without any pump at all, would act with greater steadiness and uniformity, cannot admit of a doubt. It would last for ever, and would not cost a tithe of the expense. But the second beam and frame are just as superfluous and irrelevant as the pump. For if the small crank were shifted half a turn round, to suit the

So perfect was the action of this mechanism that the fly-wheel had been wholly removed, and the engine and the whole mill-work were moving in the most smooth and effective manner. It was found that the change enabled them to give all the grinding stones a greater velocity than formerly, so that the quantity ground was greater, in the proportion of 14 to 13, and the quantity of the finest or first flour, from the same wheat, was likewise much increased; so that, both by quantity and quality, the owner of that mill was now able to "command the market." The same motion has subsequently been applied to cotton-mills with perfect success; the quality and the quantity of yarn produced being much improved.

Fig. 113.

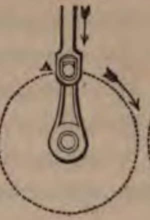


Fig. 114.

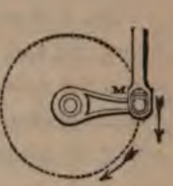


Fig. 115.

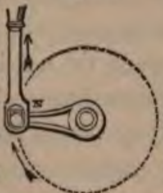
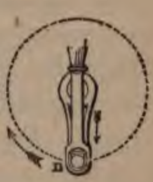


Fig. 116.



From the circumstance already noticed, that at one point the steam possesses no power of turning the crank,

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want of the beam, a mere weight hung from that crank by a long enough rod, is all that is necessary; care being taken to restrain it from swinging violently. In the specification of the patent, it is indeed suggested that a weight might be used at the end of the second beam, instead of the pump; but there is not the least hint that a weight could suffice without that beam. It is, however, proposed to make the pump serve both as an equalizer and also as the air pump of the engine; although nothing can be more evident than that it would then act badly in both capacities. Yet this proposal is the only thing having the least resemblance to a reason why a pump should have been resorted to at all.

it has been imagined that some considerable loss of the power of the steam takes place during its transmission through the crank. This is a grave error, and it has produced other errors, which we shall consider in our chapter on rotatory steam-engines.

Figs. 113 to 116 represent the crank in different positions. In figs. 113, 116, the connecting rod and crank are in the same straight line, technically called the position "on the centre," or passing the line of centres, in which the action of the steam neither tends to turn the crank in the one direction nor the other. Again, at M and N, figs. 114, 115, where the crank is acted upon at right angles by the connecting rod, it is plain that the whole force transferred through the rod is acting to turn the crank; while in the intermediate positions there are two efforts, one acting on the centre of the crank, and another to turn it round. For examining the proportion of these forces to each other, we may use the two following diagrams:

Fig. 117.

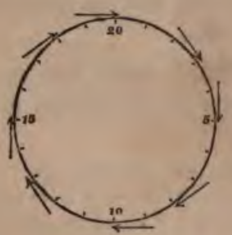


Fig. 118.

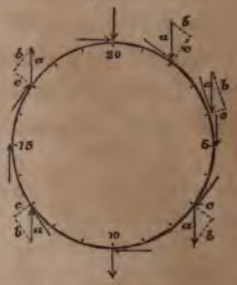


Fig. 117 represents the circle of the crank, the arrows showing the direction in which the crank-rod would require to act, in order that all its force should be undivided, and produce alone the single effect of causing revolution. Fig. 118 indicates the deviation which the actual motion of the crank exhibits from this hypothetical condition. The arrow *a* indicates the direction of the action of the connecting rod, which at divisions 10 and 20, is acting only towards the centre of the circle with no effect in producing revolution. At divisions 5 and 15 the whole effect takes place in producing revolution only. Through the first half of the circle the pressure of the rod acts wholly downwards, and through the latter half of the stroke wholly upwards. The circumference of the circle being divided into 20 equal parts, the analysis of the force is given in the figure at several of these points. At the second division, *a* represents the direction of action of the crank-rod, *b* is parallel to the direction of the circumference (or tangent) of the circle at that point, while the line *c* is directed to the centre; *a* indicating the direction of the whole force of the connecting rod, *b* representing the effect produced in the direction of the tangent to turn it round, and *c* the effect of the force of the connecting-rod acting to produce pressure on the centre of the crank: but as the centre of the crank is fixed and prevented from moving, none of the moving power of the crank is given out in producing motion towards the centre, but only in producing motion in the circumference. At the fourth division of the circumference it may be observed, that the effect of the connecting-rod is differently distributed. The whole force *a* is now more nearly in the direction of *b*, and *c* is comparatively small; showing that as we approach the end of the first quarter's revolution, the force of the connecting-rod is producing much less pressure in the centre of the crank, and pressing in a higher proportion in the direction of the revolving effect, until at last the connecting-rod being at right angles to the crank, its whole pressure acting to turn round the crank, none of it is directed towards the centre. After passing the quadrantal point 5, the crank-rod still presses downwards, as shown by the arrow *a* at point 7; but, of its two effective pressures, one represented by *b* still acts in turning round the crank, while another represented by *c*, instead of acting towards the centre, as in the upper quadrant, now produces a pressure which would draw the crank away from the centre; but as the crank is fixed, none of the motive power is employed in producing any motion of the crank away from its centre. Similar alternating effects are produced through the other quadrants; so that, while the pressure of the steam, acting through the connecting-rod upon the extremity of the crank, is divided into two effects, one of these is prevented from expending the moving force of the engine by the fixedness of the crank centre, and the whole motive power is given out only at the circumference of the crank circle in turning it round, but in a proportion of pressure that is continually varying from 0 to a maximum, and from a maximum to 0, through every successive quadrant of the circle. The amount of the variation is shown in the following table, which consists of the sines of a series of angles which increase continually by 18°, the radius being 100:—

Points in the figure.	Pressure in direction of revolution.
0 and at 20	0.00
1.........19	30.90
2.........18	58.78
3.........17	80.90
4.........16	95.11
5.........15	100.00

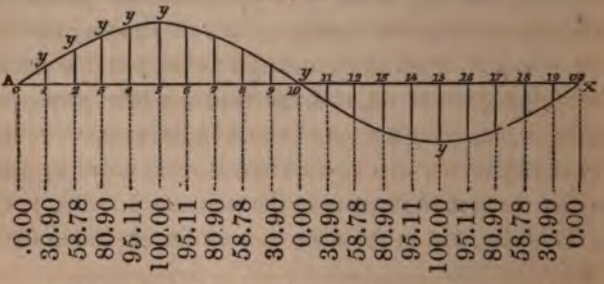
Points in the figure.		Pressure in direction of revolution.
6	14	95.11
7	13	80.90
8	12	58.78
9	11	30.90
10	10	0.00
	Mean pressure,	63.11

The mean pressure on the crank being in the table about 63 pounds, taken on an average of the whole circumference of the circle, the pressure varies from 36 pounds above the mean, to 63 pounds below it. The total pressure of the steam in the cylinder forces the connecting rod up and down through a space equal, each time, to the diameter of the circle, while the connecting rod carries the crank through a space which is equal to the whole circumference; and as the circumference of a circle bears to twice its diameter an approximate ratio of 100 to 63, it follows, that the pressures on the crank and piston are inversely as the spaces through which they move; the motive power of steam in the cylinder being 100 lbs. moved through a space of 63, and the motive power given out in the crank, being a mean of about 63 lbs. moved through the circumference of a circle which is represented by 100, so that the motive power is in the one case 100 lbs. × 63 = 6300 lbs., and in the other case 63 lbs. × 100 = 6300 lbs.

The crank is merely one beautiful exemplification of the great dynamical principle, which includes in it the law of operation of all the elements of machinery, " that in uniform motions the quantities of motive power, or *vis* *viva*, may be transferred from one point to another, through every variety of direction, velocity and intensity, by material mechanism, without being thereby altered in quantity, except in so far as friction and imperfect rigidity may diminish its amount by a certain percentage, which diminution it is the aim of all perfect construction and design, in the practical application of machinery, to reduce to the smallest possible amount." To render uniform the effective pressure given out by the crank, is the object of the fly-wheel, and of the pneumatic pump of Mr Buckle. For the same purpose many other expedients have been devised; and the following explanation is intended to facilitate the comprehension of the nature and value of these expedients.

The variation of pressure on the crank of a steam-engine may be conveniently represented by curves. Let the circumference of the circle described by the crank be represented by the straight line A X, fig. 119, and divided into any number of equal parts; let straight lines y^1 y^2 y^3, &c., be drawn to represent the amount of pressure converted into the direction of the motion of the crank, according to the line *b* in fig. 118, being the amounts represented in the line of figures, then the curved line A y y y x passing through the summit of all these lines will represent the

Fig. 119.



variation in the power of the crank at each instant of time, each ordinate y^1 y^2 y^3 being the pressure, and the area of the whole figure will represent the whole motive power, having a maximum at y^5 and y^{15}, and a point of change of direction from pressure one way to pressure the opposite way at y^{10}.

Now one method of equalizing the rotative pressure on the crank has been proposed, and is very generally adopted, viz. to make two steam-engines act on the same axis by means of two cranks at right angles to each other, so that when the one ceases to exert force, the other may be at its point of greatest force.

Fig. 120.

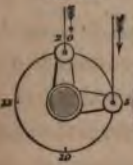


Fig. 121.

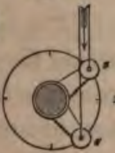


Fig. 122.

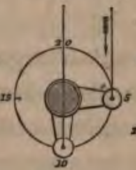
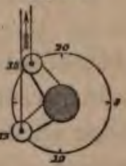


Fig. 123.

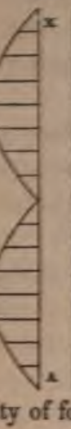


Thus in the figures 120 to 123 two cranks are represented as coming from two cylinders, and attached to the same axis, so that when the one of them is at 0, the other is at 5, when the first is at 5 the second is at 10, and so on; so that while either is on the line of cessation of force, the other is at the point of maximum.

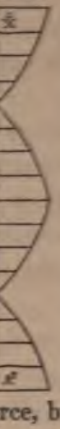
The joint effect of two such cranks may be represented by curves in the following way:—

Let the circumference of each crank circle be represented by the lines A X and A^2 X^2 as formerly, each semicircumference being divided into eight parts, and let the pressure be calculated from a table of sines, where each will be found as the sine of the arch of the circumference to which it corresponds; the numbers thus obtained being arranged on the right of the figures, so as to obtain by the two curves the representation of the varying quantity of force, but without regarding the reversion of direction. If now we place these curves together, as in fig. 126, their whole ordinates taken across from the one curve to the other, will truly represent the amount of the sum of the forces and its variation; and if we place all these ordinates from a fourth axis, we shall have truly represented, by the new curve (fig. 127) the variations of the sum of the forces of the two cranks. The figures in the third column represent the sums of the ordinates, in which it is shown that the maximum is 41 per cent. greater than the minimum pressure, even when two cylinders are made to act on cranks at right angles to each other.

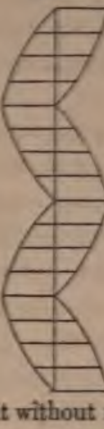
124.



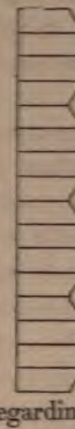
125.



126.



127.



First.	Second.	Sum.
00.000	100.000	100.000
38.268	92.388	130.656
70.710	70.710	141.420
92.388	38.268	130.656
100.000	00.000	100.000
92.388	38.268	130.656
70.710	70.710	141.420
38.268	92.388	130.656
00.000	100.000	100.000
38.268	92.388	130.656
70.710	70.710	141.420
92.388	38.268	130.656
100.000	00.000	100.000
92.388	38.268	130.656
70.710	70.710	141.420
38.268	92.388	130.656
00.000	100.000	100.000

The whole of this calculation is summed up in the following formula:

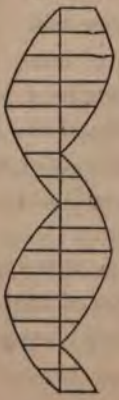
Let r be the radius of each crank,
x the effective leverage of one,
$\therefore \sqrt{r^2 - x^2}$ is the effective leverage of the other,
and $x + \sqrt{r^2 - x^2}$ the sum of the pressures:

from which we obtain, by differentiating
$x = \sqrt{r^2-x^2}$ in the case of a maximum,
and when $x = 0$, the sum $x + \sqrt{r^2-x^2}$ becomes $= r$
or when $\sqrt{r^2-x^2} = 0$, $x + \sqrt{r^2-x^2}$ becomes $= r$
and when $x = \sqrt{r^2-x^2}$, $x + \sqrt{r^2-x^2}$ becomes $= r\sqrt{2}$
$= 1.414\ r$.
Hence the point of greatest pressure is at 45° from the minimum and the minimum sums at the termination of each quadrant, the maximum being to the minimum as the square root of 2 to unity.

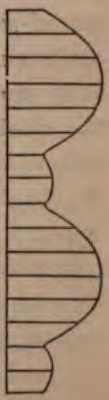
It is obvious, then, in conclusion, that with two engines the variation above the mean amounts to about 126—141 =15 in 126, or about eleven per cent., and that the decrease below the mean amounts to twenty per cent.

It is a matter of some difficulty to decide at what angle the cranks should be placed in a double engine, so as to give the best effect. If we place them at a greater angle than 90° apart, the minima become small, and the maxima, however, are by no means sudden. If we place them at a less angle, the maxima become excessive; and although the minima be larger, the maxima are also larger. The annexed diagrams, 128, 129, show the effect of these two methods.

Figs. 128.



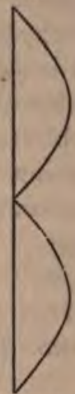
129.



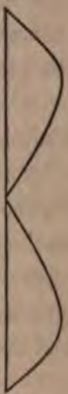
When a lever intervenes between the crank-rod and the piston-rod, new irregularities are introduced. The variation in the direction of the connecting link, and in the position of the lever-ends from a straight line, introduces modifications of these effects of a serious nature, but not of a large amount. It is worthy the attention of practical men to consider these variations, and the manner in which they affect the uniformity of the pressure. They affect it by way of increase at the beginning and end of the stroke. By proper arrangements, these very obliquities may be rendered very considerable improvements in the working of the engine. It should also be observed that the stroke of the piston and crank will not remain of the same length.

The agency of the crank in transmitting a force parallel to the piston-rod has been represented by the curve of sines, as in fig. 130. But if we represent in a similar way the pressures produced by the obliquity of the crank-rod, we shall find the form become that given in the following figures. Fig. 131 represents the variation of pressure with a crank-rod of four times the length of the crank, fig. 132 with a crank-rod of double the length of the crank, and fig. 133 with a crank-rod equal to the length of the crank.

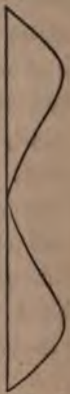
Figs. 130.



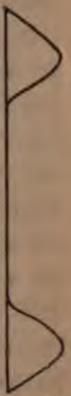
131.



132.



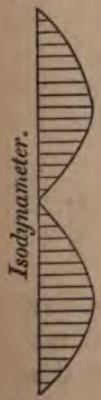
133.



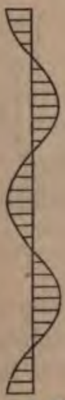
It is obvious, that with the shortening of the crank-rod, the irregularity of the motion becomes very great. Two maxima rapidly succeed each other, and these are wide apart from the next pair. Thus two violent pressures succeed at a short interval, and a long pause intervenes, when the force is very small.

By the same system of curves we may proceed to examine the pneumatic equalizer of Mr Buckle. Let the rotative pressure of the crank be again represented, as formerly, by the curve in fig. 134. And let the rotative pressure of the pneumatic crank of the equalizer be represented by the curve in fig. 135, lying on alternate sides of the axis, so as to show the alternate coincidence with, or opposition to, the action of the steam-crank. Then if we place the two axes as in fig. 136, the lines between the two curves will represent the sums of the pressures; and if we set off these intercepted parts in a third curve, we shall get the line representing the variation of the resulting force corresponding to the sums and differences of the former ordinates. The values of these are given in columns of figures on the right through one quadrant. The mean value 63 is in this case exceeded by 19 per cent., and is receded from below by nearly 20 pei

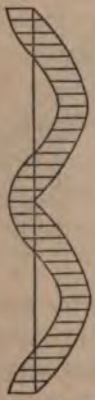
Figs. 134.



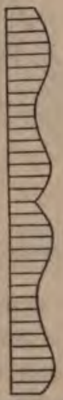
135.



136.



137.

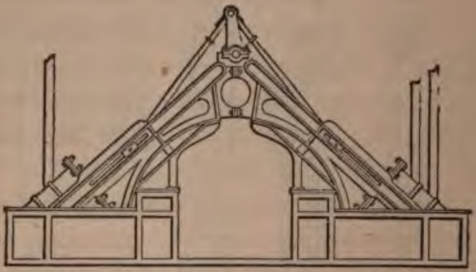


0.000	50.000	50.000
19.509	46.194	65.703
38.268	35.355	73.623
55.555	19.134	74.689
70.710	00.000	70.710
83.147	19.134	64.013
92.388	35.355	57·033
98.078	46.194	51.884
100.000	50.000	50.000

cent. The deviation from the mean pressure is not, therefore, greater than 20 per cent., and the equalization produced by Mr Buckle's pneumatic equalizer is as efficient as a pair of engines, and much less complicated and expensive.

Still, however, it is to be noticed, that as there is a variation of force amounting to about 20 per cent. above or below the mean, with a pair of engines as well as with the pneumatic reservoir of power, it is obvious that the combination of a fly-wheel with either of these systems of arrangement, would be required to obtain the nearest possible approximation to uniformity in cases of delicacy.

Fig. 138.



Instead of using two cranks for applying the force of two steam-engines to the same axis of revolution, two engines have been used with their cylinders laid at right angles to each other, and having their connecting rods applied to the same crank. For an engine of this kind, fig. 138, Mr Brunel obtained a patent; and we have seen his machine working in a satisfactory manner. An arrangement of a similar description has also been introduced in steam-boats by M. Cave of Paris.

Of the Connecting Rod and Parallel Motion.—In considering the agency of the crank in modifying the force and velocity of steam, so as to connect its direction and distribute its force in the manner required to produce a rotative motion in the machinery, from the original reciprocating motion of the piston in the cylinder, we have hitherto avoided the introduction of another important element, by which a further variation of force and of motion is produced. The connecting rod is a rigid bar of metal which conveys the motion of the piston from the piston-rod to the crank either immediately or through the interposition of the lever or beam; and as the connecting rod, in doing so, takes various directions different from those either of the piston-rod or of the crank, there is an obliquity of pressure produced at both extremities of the connecting rod, which gives rise to a variation of force and of direction, which must be practically provided for, and carefully appreciated in quantity, in so far as it may affect the ultimate operation of the machine.

There are two ways in which the motion of the piston-rod is most commonly transferred to the crank; either immediately through the connecting rod,* as in fig. 139, or through the medium of the great lever, as in fig. 140; both ends of that lever describing circles around its middle fulcrum as a centre, and the head of the piston-rod being connected with the one end of the lever by means of an iron strap or connecting link. From inspection of the figure, it becomes plain that the connecting rod or link is never, except at two points, in the same straight line with the piston-rod, so as to propagate its unmodified force to the crank, but that in these oblique positions it would produce a lateral motion in the end of the piston-rod which would not only be a waste of power in producing motion in a place where it is useless, but would have the effect of continually bending the piston-rod in opposite sides, so as either to break it, or materially to impair its working. In the first of these figures, P p being the direction of the piston-rod, p R that of the crank, the force in the piston-rod in the direction p a becomes resolved into two parts p R and p c, p R being effective in the direction of the crank-rod, and p c tending only to give lateral motion to the piston-rod, or else to bend it, or break it across. And so also in the second figure there is a similar separation of pressure.

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* Crank engines without beams, or as they are also called, direct action engines, are daily coming into more general use; so that probably at no distant day the beam will only be found in such engines as have no crank.

Fig. 139.

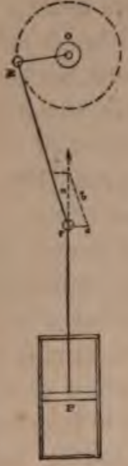
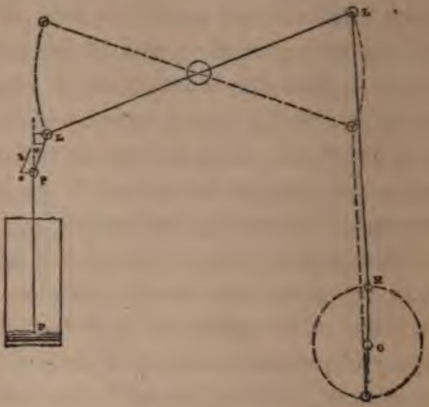


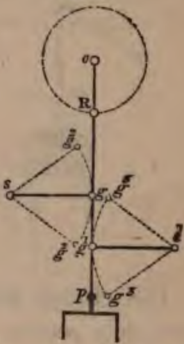
Fig. 140.



To prevent these oblique pressures from wasting the power of the steam, by producing lateral, useless, or injurious motions, is the object of a series of contrivances called parallel motions, or parallel guides. The most notable of these we owe to Mr Watt.

Let it be supposed that we desire to prevent the top of the piston-rod p, fig. 141, from being moved by the obliquity of the connecting rod p R, either towards the right or the left, then it is accomplished in the following way. A fixed support, s, is found on one side of the piston-rod; and another on the other s^1, at equal distances from it, and two parallel bars $g\ s$ and $g^1\ s^1$ are placed between the piston-rod and these points, so that it may be steadied between them. These parallel bars are made so as to revolve freely round the points s, s^1 as centres, each of the ends g, g^1 describing the circles $g\ g^2$, $g^1\ g^3$, from which it is evident that if these rods were directly attached to the piston-rod at g and g^1, they should have the effect of keeping the point p in the straight line $o\ g\ g^1\ p$. As these bars $s\ \ g$ and $s\ g^1$ must describe circles round s and s^1, they would, in the positions $s\ \ g^2$, $s^1\ \ g^3$, deviate altogether from the straight line of the piston-rod; but as the one will act nearly as much in the one direction as the other in the opposite, it occurred to Mr Watt that, by connecting their extremities with a link, $g\ g^1$, and attaching the piston-rod, not to the ends of the guide bars, but to the middle of this link, the point p might be prevented from deviating to any appreciable extent from the straight line. This is accordingly produced in a very

Fig. 141.



simple way. The following figures, 142, 143, 144, show the effect of these links in various positions.

Fig. 142.

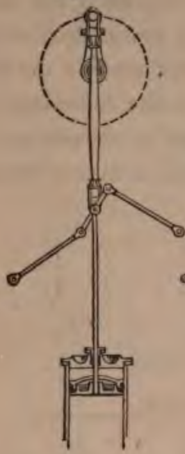


Fig. 143.

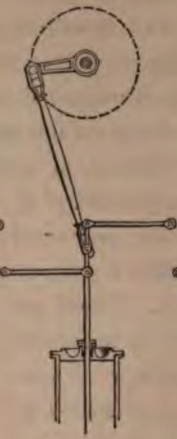
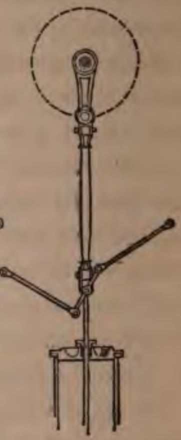


Fig. 144.



This elegant and simple contrivance is not, however, absolutely perfect. At the best only a part of the line which it describes makes an approximation to a straight line of scarcely sufficient length, and beyond which the stroke of the piston cannot be increased without being seriously deranged. Nor can this be remedied, but by constructing the apparatus on a scale so large as to be highly objectionable. Thus in the above arrangement the point *p* is not kept perfectly in a straight line, but is, on the contrary, compelled to deviate from it so as to describe a looped curve. The nature of this deviation will become very evident if we suppose the parallel motion to be altogether detached from the piston-rod, and the motion of the parallel bar and link carried to its extreme, as in the following figures, 145, 146. A pencil being used to trace the motion of the middle point, p will describe, not a straight line, but a curve p x y. When we carry the rods up to the position represented in figure 145, where the bar g s comes into the straight line with the link g g, the point p deviates from the straight line by turning to p^1, and this is reversed in the opposite extreme. In figure 146 the deviation is much greater when the link g g comes into the same line with the other bar g s, and is also reversed in the position at the bottom of the figure. By the time the links have been returned to their primitive position they have described the curve x p y.

Fig. 145.

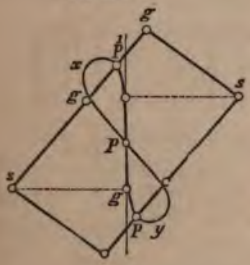
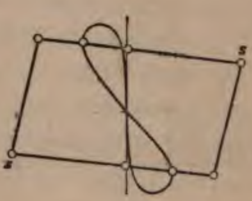


Fig. 146.



It is important to diminish this deviation which increases more rapidly than the square of the length of the stroke. Having ascertained the greatest deviation at the end of the stroke, and also at $\frac{1}{8}$th part of the stroke from the middle, bring the centres s and s nearer each other by a quantity equal to the deviation at the said 8th part, and the greatest deviation will now be reduced to less than one quarter of its former amount: the curve will now become a line of the sixth (eighth?) order.

The parallel motion of one point having thus been secured, it is easy to transfer it to any other point. This is most commonly done by a jointed parallelogram. Thus, to transfer it to a point in connection with *s g* prolonged to *t*, (figs. 147 to 149,) take a second link *t q*, equal to *g g*, and a second bar, called the parallel bar *g q*, equal to *g t*, the corner *q* of the parallelogram will give a motion *t q*, similar to *p*. Figs. 150, 151 show the parallel motion transferred to a point still farther from the original point.

Fig. 147.

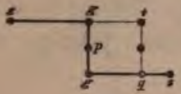


Fig. 148.

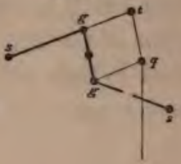


Fig. 149.

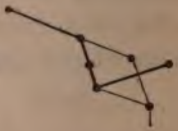


Fig. 150.

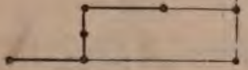
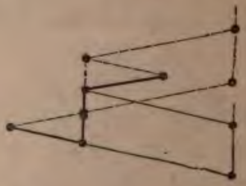
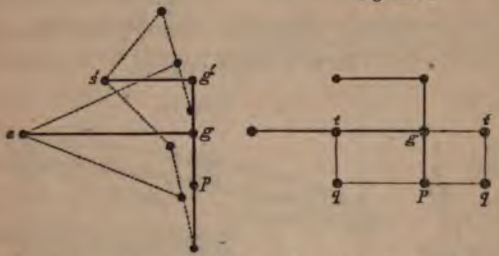


Fig. 151.



Another form of Mr Watt's invention consists in placing two bars in the same direction, with such a difference in their length as may afford the means of compensation. Suppose that the point *p*, fig. 152, is to be guided to move in the straight line *p g g′*; *s*, *s′* are points on the same side of the required direction of motion, and *s g*, *s′ g′* are the differential bars connected by a link *g′ g*, which is prolonged to *p*. The dotted lines of the figures show the bars in different positions. The point *p* does not describe a straight line, but a curve, like figs. 145, 146. The motion of the point *p* may be transferred to a distance, as in the former instance, by a jointed parallelogram *g p t q*, fig. 153. All these parallel motions may be inverted, and indeed generally are inverted in steam-boat engines. For practical examples of them, the reader may consult the plates.

Fig. 153.



All these motions as well as the first being imperfect, various plans have, from time to time, been adopted for remedying the evil. In American steam-engines, Watt's parallel motion has been to a great extent abandoned, because in them long strokes and long cranks are preferred; and because in such cases the deviations of the point *p*, that is to say, of the piston-rod, from a straight line, would, with Watt's method, become excessive. Watt and his assistants and followers were perfectly aware of this, and hence were led to construct beams, and connecting rods, and parallel motions, of *very great length*, so as to diminish the evil as far as possible. This has, of course, the effect of rendering the whole engine both bulky and expensive, and is, therefore, in many cases inexpedient.

The American engineers, therefore, use the sliding parallel motion; that is, they have substituted for the radius bars of the parallel motion of Mr Watt, a sliding bar or groove in which the top of the piston-rod is guided.

The head of the piston-rod *p*, figs. 154, 155, is enclosed between two flat surfaces, or between two parallel iron bars, which are kept in the vertical position by means of stiff-framing: on these it slides, or to diminish the friction, wheels may be added; but there are reasons why such wheels do not in practice work very well, and the plain slide is therefore preferred.* In fig. 154 we have represented this motion as applied to an engine of the simplest form, and in fig. 155 to a beam engine.

Fig. 154.

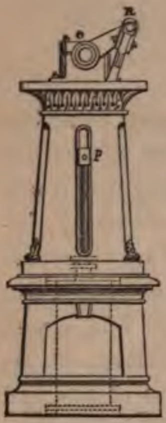
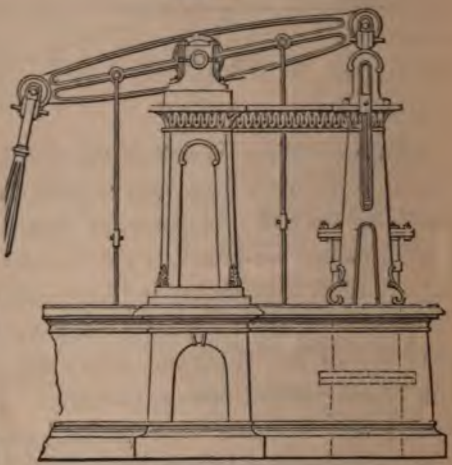


Fig. 155.



Another species of parallel motion was, we think, first adopted in America; but it has also been used in this country. It is the engine with vibrating pillar.

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* Wheels of this sort would probably answer, if means were used to keep them always moving at the same rate as if they were continually rolling on the surfaces against which they are meant to act; so that when a pressure came suddenly on a wheel, it would be in readiness with the proper rate of motion. Fig. 3, Plate II. gives an example of a parallel motion with friction wheels. Springs to press the wheels and surfaces together would produce the required motion of the wheels; but nothing must be allowed sensibly to yield when the aid of the wheels is required.

The pillar, which supports the beam or lever, instead of being fixed in an upright position, has a joint at the bottom, as will be seen in fig. 156, on which it and the beam and the crank-rod perform a joggling motion backwards and forwards during each stroke. The motion is of the following nature:—The point *s*, fig. 157, is fixed: so is *s′*; *s g* and *s′ g′* are movable bars; *p g* is $\frac{1}{2}$ of *p g′*. The point *g* describes a circle round *s*, and *g′* round *s′*: hence *p* describes the curve *p s p′* of the sixth order. The oscillation of the moving mass of the engine in alternate directions, with a sudden jolt at the end of the stroke, renders this a bad engine when made on a large scale; and it is obvious that the deviation of the piston-rod from the straight line is very great.

Fig. 156.

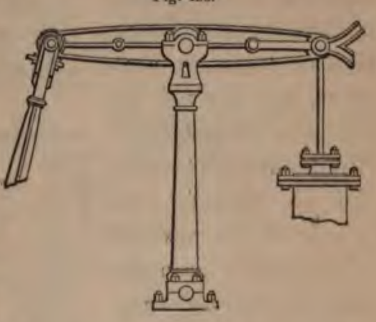
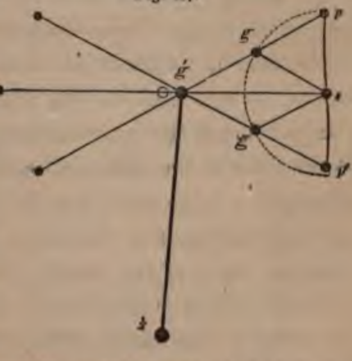
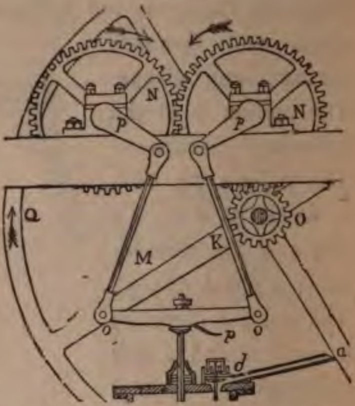


Fig. 157.



A very elegant parallel motion was invented by the Rev. Dr Cartwright, and applied by him to the steam-engine so early as 1797. Two equal toothed wheels N N, fig. 158, work into each other, and their axles are furnished with two equal cranks similarly situated and connected by rods with the extremities of a cross bar, to the middle of which the piston-rod is joined. These cranks and connecting rods being always in similar positions on opposite sides of the piston-rod, the obliquity of their actions balances each other, and the rod describes a straight line.* But it is difficult to make and to maintain the wheels of this machine in the state of accuracy and perfection necessary to its working well.

Fig. 158.



The cycloidal parallel motion is one of high geometrical beauty. It was invented by Mr James White, and published in his " New Century of Inventions" in 1801. It depends on this principle that an encycloidal curve, described by one circle rolling within another, approaches a straight line as the inner circle becomes more nearly equal in diameter to the radius of the outer one. To apply this principle, a large wheel *q q*, fig. 159, with teeth on its inner circumference, is fixed on a frame concentric with the axis and circle of the crank. N O is a wheel with external teeth, which is fixed freely on the crank-pin, and *p* is the point of attachment of the piston-rod *p l*. By this arrangement the small wheel N O is compelled, by the pressure of the piston-rod upwards, to roll round the great circle, ascending on the one side and descending on the other, so that the distance of the end of the piston-rod from

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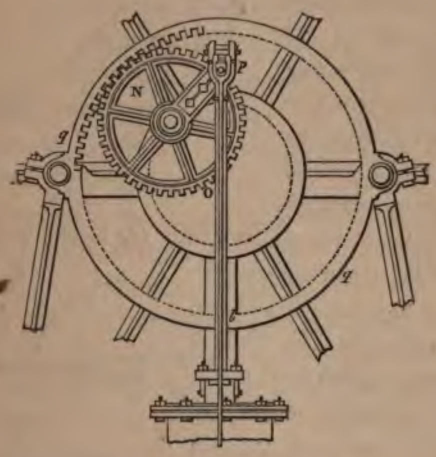
* The peculiar sort of engine partly represented in fig. 158 was intended to be worked by the vapour of alcohol, which, as a moving power, is never to be compared with steam. See Phil. Magazine for July 1826.

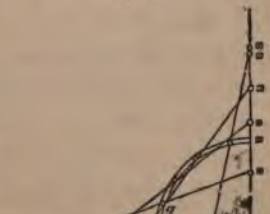
Fig. 159.



the point of contact of the circles is always equal to the distance of the circle from the diameter; (or, $n \mp r.\ \sin.\ e = \pm \frac{1}{2} r.\ 2 \sin.\ e.$) and thus the straight line is always preserved. We have seen this motion working very well.

But the principle which furnishes the most perfect parallel motion, is one which, although not new, we have never seen applied to practice. It is well known that the locus of the extremity of a straight line, the middle of which moves in a circle, the other end being confined to one straight line, is also another straight line at right

Fig. 160.



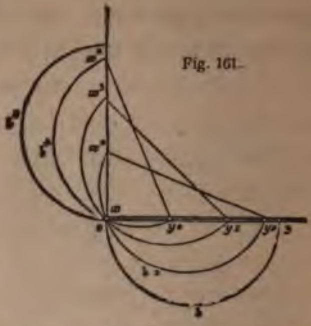


Fig. 161.

angles to the former.* Let a straight bar $x\,y$, fig. 160, be placed with one end y confined in an horizontal groove $a\,s$, and let a pin in the middle g be allowed to slide in a circular groove $y\,g\,x$, then the end x will always describe a straight line $s\,x$ perpendicular to the first. Or it may be thus modified. If the arc of a semicircle have one of its extremities placed in a given straight line, while it moves along a given fixed point, the other extremity of the arc will describe another straight line at right angles to the former. Let a semicircular round bar $y\,b\,x$, fig. 161, be allowed to slide through a fixed centre at s, the one end y sliding in a groove, or along a bar $s\,y$, then the point x will describe the perpendicular $s\,x^4$, a perfect straight line.

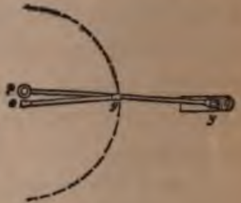


Fig. 162.

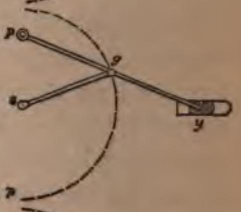


Fig. 163.

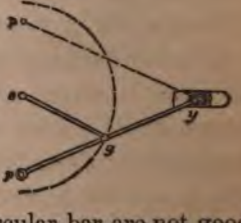


Fig. 164.

To put this in practice in a form which shall not deviate widely from received forms of construction, is not difficult. The semicircular groove and the semicircular bar are not good constructive expedients. But if we take a radius bar *s g*, figs. 162, 163, 164, fixed at a centre *s*, so that its end *g* describes a circle freely round it; and if we take a rigid bar *p y*, of double the length of *s g*, and united to it at *g*, then the middle of *p y* being thus constrained to move in the circle round *s*, we have only to permit *y* to slide freely in an horizontal groove, and the point *p* being carried up and down, will describe the straight line *p s p*. Fig. 165 shows the application of this motion to the simple engine, and fig. 166 to the beam engine.

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* But it must always be remembered, that this is true only when the diameter of the circle is equal to the first line.

Fig. 165.

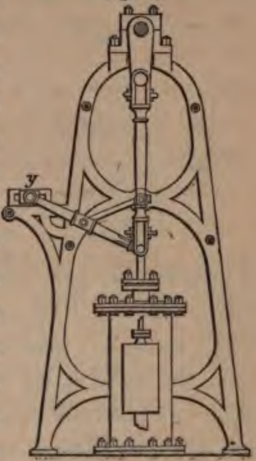
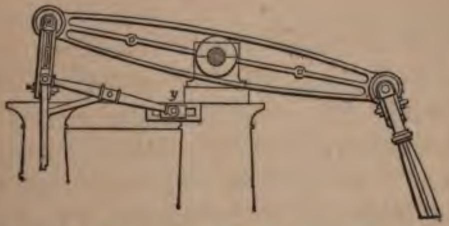


Fig. 166.



The late Mr Oldham of the Bank of England showed us an application of this principle, of which he had made a model. He added a refinement which diminishes the friction at *y*, while it introduces an infinitesimal error of the second degree. To the end *y* he attached Watt's parallel motion, as represented in fig. 168, *s g*, *g s* being the radius bars, and *g y g* the connecting link on a small scale, the point *y* is by this parallel motion guided in the horizontal direction. Instead of this refinement, which only produces infinitesimal error, we propose, if it were required,

Fig. 167.

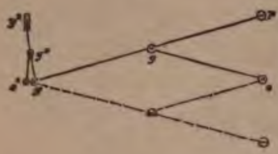
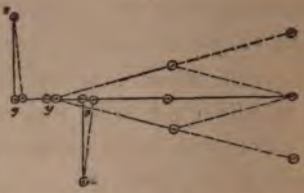


Fig. 168.



to preserve the principle without error, and to introduce only infinitesimal friction. This we accomplish by placing a secondary geometrical motion like the primary one upon the point y, fig. 167, so that its motion may take place in a perfectly straight line. The effect of the friction will thus become an infinitesimal of the third order. These last refinements are, however, of a higher order than the degree of practical precision in the steam-engine usually requires.

Such is the mechanism which the obliquity of the direction between the connecting rod, or link, renders necessary to prevent any of the motion, propagated through them, from being expended in producing oblique transverse motion in the top of the piston-rod. Still, however, the motion of the piston-rod is modified by transference in an oblique direction, and we have now to consider the nature of that modification. Suppose the crank O R to have the position in fig. 169, where the connecting rod p R is at right angles to it; then the connecting rod p R makes with the piston-rod P p an angle O p R or θ. The force F therefore, acting along the piston-rod P p, being represented by the length of p x, and x y, and p y being drawn parallel to R p and R x, we see that the line x y or p R =

$\frac{\text{F}}{\cos.\ \theta}$ represents the force in the piston-rod along the crank-rod, tending to make it revolve, while $p\ y = \text{R}\ x =$

Fig. 169.

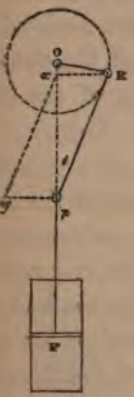


Fig. 170.

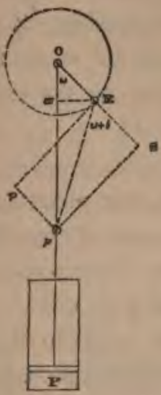
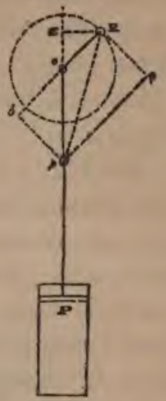


Fig. 171.



$\text{R}p \sin.\ \theta = \text{F}.\frac{\sin.\ \theta}{\cos.\ \theta}$ represents the amount of pressure sustained by the parallel motion.

Thus we have a true representation of what takes place when the connecting rod, instead of being in a line with the piston, or parallel to it, is at right angles to the crank; and in this case the whole force communicated in this oblique position to the crank-rod, acts immediately and entirely in turning round the crank. But at other points, such as are given in figures 170, 171, the motion is again modified by the obliquity of the direction of the connecting rod p R to the crank O R. If O R be prolonged to S, and from p a perpendicular dropped upon it, and the parallelogram R ϱ p σ completed, we shall have the diagonal force p R resolved into R σ and R ϱ; whereof R ϱ alone tends to turn round the crank, $R\ \sigma$ producing only pressure towards the centre. In this case the angle $p\ R\ \sigma$ is equal to the two interior angles of the triangle $p\ R\ O$, that is to $\omega + \theta$, the sum of the angles of the connecting rod and crank with the line of the piston. Hence the whole force in the connecting rod becomes resolved into $p\ R. \cos. (\omega + \theta)$ and the whole force of the steam on the piston-rod becomes on the extremity of the crank, $F. \frac{\cos. (\omega + \theta)}{\sin. \theta}$

The Piston.—The next elementary part of the steam-engine, upon which much of the efficiency of its operation depends, is the piston. Pistons were at first very rude implements for steam to work with. A large block of wood cut round so as pretty nearly to fit the inside of the cylinder, and driven very tight, was considered a sufficient obstacle to resist the passage of the steam or air, until the former had performed its duty of driving the piston from the bottom to the top; or the latter of driving it from the top to the bottom of the cylinder: a quantity of water was also kept on the top of the piston. It next became usual to cover this piston with leather, but which was soon dried up by the heat of the steam and deprived of the requisite pliability. The next step was to make the piston of metal, like the piston of Otto Guericke's atmospheric engine, and then to make a groove around this piston, which was filled with bands of plaited hemp, now technically called a gaskin, so put together as to be spongy and elastic, and to interpose this elastic substance between the piston and cylinder, so that the hemp, yielding to the inequalities of the cylinder, should fill them up without permitting the steam to escape. This has been successfully used for a long period, and, where the cylinder is in good condition, used with advantage: and it is still very extensively employed. Instead of using a solid piston with a groove for the hempen packing, it was found better in practice to construct the piston as shown in fig. 172. The lower part of the piston is formed of a plate attached to the piston-rod; the under-edge of this plate is of a diameter a little less than that of the cylinder, and it gradually curves inwards, so as to form the lower portion of a groove for the packing. The upper part of the piston consists of a plate with a similarly curved rim, completing the groove. This upper plate is called the piston-cover, and is attached to the lower plate or body of the piston by screws. In the groove are carried round bands of soft plaited hemp or gaskin, which fill up the cavity; and as the gaskin wears, the upper plate is screwed closer to the lower one, and forces the packing against the sides of the cylinder. The piston is represented in its place in figure 174.

Fig. 172.

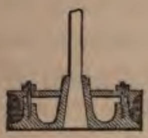


Fig. 174.

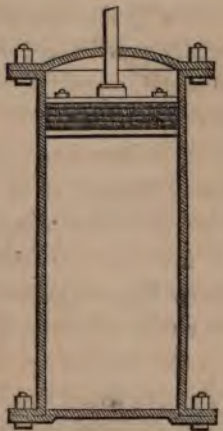
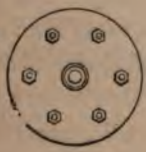


Fig. 173.



The only fault of this hempen packing, is its liability to wear out, and become rigid and unelastic. A plan was next adopted of protecting this hemp, and still using its elasticity. Around the piston, in front of the packing and enveloping it, two brass hoops, fig. 176, with slits in them, were placed, to protect it from contact with the cylinder. These slits allowed the hoops to enlarge and contract their diameter, in correspondence with the inequalities of the cylinder; while by the elasticity of the hemp, they were kept continually pressed out in contact with the surface. This simple metallic packing is represented as applied to the piston in figure 175.

Fig. 175.

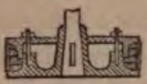
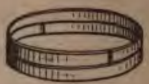


Fig. 176.



A still more independent metallic packing is produced in the following manner, so as to dispense altogether with the elastic action of the hemp. Large metallic belts of considerable thickness are cast, so as to form solid rings, about a hundredth part greater in diameter than the inside of the cylinder they are to fit, and turned on a lathe truly cylindrical to that diameter. A small portion is then cut out of the circumference of each ring, so as to make them open hoops like those represented in the last figure; and the two open ends are then forcibly brought together, until their diameter is just such as to admit them into the cylinder, their ends being now in contact so as to form complete rings, and they are again placed in the lathe and turned truly cylindrical. By this arrangement it is brought about, that the elasticity of the rings continually urges them outwards, towards their original diameter, and so dispensing with the elasticity of the hemp, forms a packing wholly metallic. This is employed on a large scale by some of the very best engineers in this country, and is greatly to be recommended for its simplicity. Of course the break in the ring would allow steam to pass; but this is avoided either by interposing a metallic tongue at the break, or by using a number of rings, so that the break in one of them may be opposite to the sound portion of the other.

Another form may be called the wedge metallic piston. The rings are cut into a number of parts, and are pressed upon the cylinder by wedges, which again are kept in their places by springs; and so it is supposed that a more perfect adaptation is gained of the parts of the ring to the cylinder. This is certainly the case; but the ring is much more complex than in the other form:—

Fig. 177.

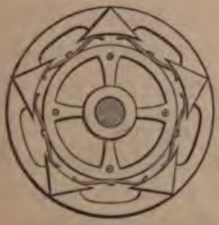
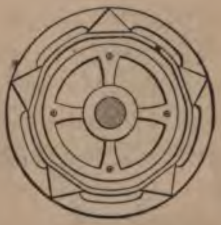


Fig. 178.



In fig. 177, wedges are shown to be inserted behind the rings, with springs behind them, forcing them outwards; and in figure 178, a single elastic hoop is substituted for all those springs. Springs without wedges are also in very common use for metallic pistons with divided rings, double sets of rings being used, and the springs pressing directly on the segments of the metallic rings, as in figs. 179, 180.

Fig. 179.

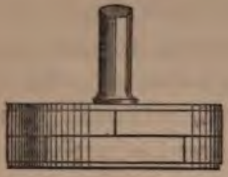
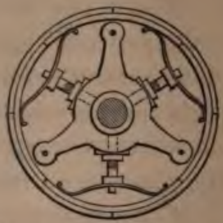
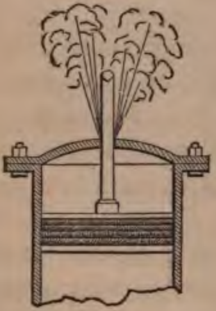


Fig. 180.



A simple aperture in the cylinder-cover to permit the passage of the piston-rod, as in fig. 181, could not be made steam-tight: so that to prevent the escape of steam, a stuffing-box has to be employed. This consists of a box cast round the whole of the cylinder-cover, fig. 182, in which is laid, around the piston-rod and in contact with it, a large quantity of hempen-packing. This packing is lubricated with oily matter, and the ring, fig. 183, is then placed on

Fig. 181.



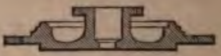


Fig. 182.

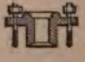


Fig. 183.

the top of it, and pressed down by screws, so as to squeeze the stuffing into every crevice. Stuffing boxes of this description are employed wherever it is necessary to pass a moveable rod out of a vessel, or into it, without permitting the escape of the steam. Thus there is one at the entrance of each valve-rod into the steam-chest of the cylinder valves, and also, wherever a moveable rod passes into or out of a boiler.

The governor is an appendage to a steam-engine, of much value in regulating all its applications to the production of uniform revolving motion. It is merely a modification of an apparatus similar to the pendulum, and by which Huyghens once attempted to regulate a time-keeper instead of the common pendulum. If we suppose the axis A *x*, fig. 184, to revolve along with the ball B hung by a thread from *x*, and also with two pieces of iron, *x* C, *x* C, bent so as to form cheeks, of a form called the cycloidal curve; then when the string B *x* comes in contact with those cheeks, the ball will perform each revolution in the same time as it would make two oscillations if merely swinging as a common pendulum; that is, if there be 39·1 inches from the centre of B to *x*, the pendulum will revolve once in two seconds. If, however, the ball B be suspended from *x* by a straight bar, such as B *x* in figure 185, the line B *x* in deviating from A *x* will describe the circular arch A B, instead of a cycloid as formerly, and the time of oscillation will vary as the ball recedes from A, the revolutions being more rapid at *b* than at B. If in the position B, the perpendicular height *x* C be 39·14 inches, then will the revolution be performed in two seconds, or at the rate of 30 per minute; while at *b* they will be performed in less time, and between B and A more slowly. The height C

Fig. 184.

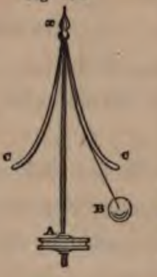
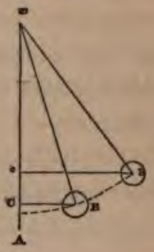


Fig. 185.



x for any required number of revolutions is equal to the length of a simple pendulum, which will give double the number of vibrations in the same time. If the mass of the ball and rod were supposed to be collected into a point, the length would be had by the following easy rule:—

Divide 35226 by the square of the number of revolutions per minute, and the result is the height $C\,x$.* Thus to find $C\,x$ for 30 revolutions per minute:—

$$30 \text{ squared} = 30 \times 30 = 900)35226($$

$$\text{required height} = 39{\cdot}14 \text{ inches.}$$

The regulation of the engine by the rate of the admission of steam to the cylinder is effected in the following manner:—

The balls B B, fig. 186, are suspended by rigid bars from the fixed joint or centre x. These bars being prolonged to $k\,k$, are joined by links $k\,y$ and $k\,y$, to a moveable socket y, which can slide up and down the axis. The straight lever $y\,p$ is acted on at one end by y, and at the other it draws up or pushes down the handle of a circular disc v, so as either to close or open it to different degrees; this disc, called the throttle valve, is placed within or in connection with the steam-pipe that supplies the cylinder, so that if the engine should at any time move too slowly, from having too much work to do, the balls will collapse, raise up y, and open v to the fullest extent, as at 4, in the small sectional figure to the right; 3 being the mean position; while, on the other hand, should the engine, from its work being taken off, go too quickly, the balls would fly off from the axis, bring down *y*, and close the valve to 2; or if it had happened, as by an accident, that the load was suddenly withdrawn, close the valve altogether, as at 1 in the side figure. Instead, however, of the bars being always, as here, prolonged above *x*, they have frequently the joints *k k* placed below *x*, and the socket *y* below these again, as in fig. 187, and in several of the plates.*

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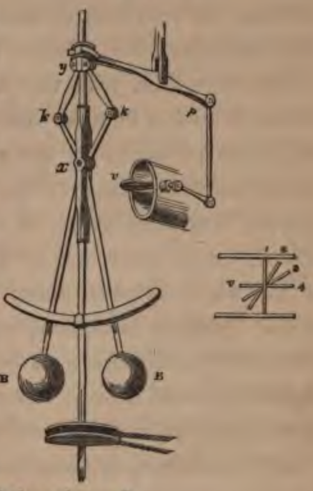
* Although the mass is far from being collected into a point, yet owing to a compensation of errors the rule as now qualified will be a tolerable approximation to the truth. For while the centre of oscillation of the ball alone would lie below its centre of gravity, that of the rod would be considerably higher: so that, if the calculation be made for the centre of the ball, it will be sufficiently correct for practice; because the rods are provided with screws to adjust the positions of the balls.

Fig. 186.



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* Thus far the governor has been regarded simply as a conical pendulum. But as long as the balls are at neither limit of their range, they are continually vibrating to and from the spindle, and so much the more as they are revolving more rapidly. This arises chiefly from the frequent variations in the centrifugal force of the balls naturally exciting them to vibrate to and from the spindle; especially since there is nothing in the apparatus which has any tendency to prevent such vibrations. The consequence is, that the throttle-valve is kept in a state of perpetual oscillation, and must therefore act with great irregularity in admitting steam to the cylinder. Many attempts have at different times been made to remedy this defect in the governor, but with no great success; for so little regard has generally been paid to the real character of the evil, that for the most part some remedy has been applied which seriously interferes with the sensibility of the governor; such as overpowering it with friction, or using something which causes the throttle-valve at one time to stick fast, at another to move too far with a start, and there again to remain immovable. Cures like these are incomparably worse than the disease.

A substitute for the governor, depending on the resistance of the air and having nothing to do with the conical pendulum, has been invented and patented by Mr Hick of Bolton. A very oblique screw is formed on the usual upright spindle. To this is fitted a heavy screw nut, or socket, furnished with two horizontal arms and vertical vanes, in such a manner that when the spindle revolves rapidly, the resistance of the air on the vanes retards the socket, so that owing to its not revolving so fast as the spindle, it rises by means of the screw, and at same time lifts the usual horizontal lever. When again the motion of the whole becomes more languid, the weight of the socket causes it to descend on the spindle. But it is rather doubtful if such a governor would possess sufficient sensibility; and it must to a certain extent be affected by any change in the density of the air.

Of Condensing Apparatus.—The parts of the condensing steam-engine which we have hitherto examined, are in all respects identical with those of the high-pressure steam-engine. The characteristic difference consists in

A very simple mode of effectually preventing the vibrations of the balls, and not liable to the above objection, would be to fix upon the horizontal lever of the governor, (prolonged if necessary,) two heavy weights, with a considerable distance between them, and such that their common centre of gravity might be in the fulcrum of the lever. Then it is evident, that while these weights would offer no sensible resistance to the lever beginning to move slowly, they would by their inertia so embarrass any tendency to rapid vibration as to prevent it from ever taking place. In this manner, the lever and valve could always be moved slowly with perfect ease; neither at one time sticking fast, nor at another moving too far with a start. In situations where there might not be room to lengthen the horizontal lever, the weights might be put on the ends of a long bar fixed at any angle across the lever and close by the fulcrum, which must still be the centre of gravity of the weights.

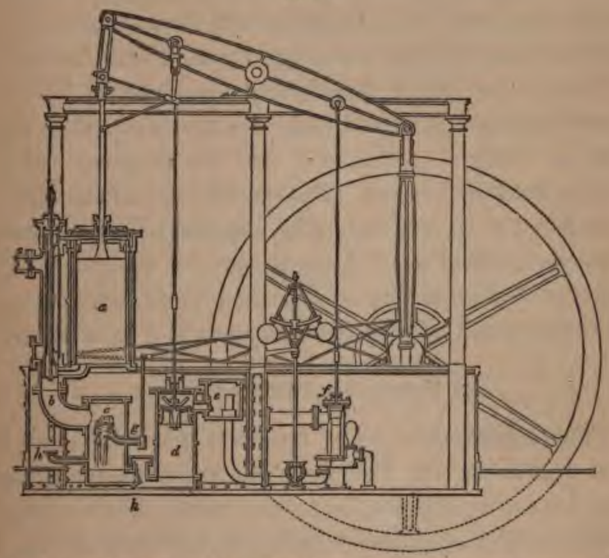
the manner in which the steam is disposed of after having done its work, and in the apparatus required for the purpose. In the high-pressure engine, the steam is discharged from the cylinder simply by allowing the entering steam to press the piston upon the outgoing steam, and force it through the eduction-pipe into the open air. Now, it requires considerable force to effect this: we know that the atmosphere must be pushed away before the steam with a force of about 15 lbs. on each square inch of the surface of the pipe; and therefore this much of the force of the steam, which is a balance for the air, that is, an atmosphere of steam, is consumed or thrown away in this employment. In the condensing steam-engine, this atmosphere is saved. The steam being liquefied almost instantaneously, a vacuum is formed on one side of the piston, and that part of the power which formerly was spent in the useless labour of forcing the steam into the air, is now employed in useful labour.

If, therefore, we take a high-pressure engine, such as already described, and if we desire to form it into a condensing steam-engine, we must add to it a large reservoir of cold water, named the cold well, such as is described in one of Watt's steam-engines, in the historical part of this treatise; and in this reservoir we must place a close vessel having an aperture or small pipe in it, from which a jet of water shall play and spread through the interior, so as to form a condenser, into which the eduction-pipe shall conduct the steam from the cylinder. The quantity of cold water thrown into this vessel to cool it, will require to be six or eight times as much as is boiled off in the shape of steam. Attached to the condenser is a blow-through valve, opening outwardly, which allows the whole condenser, before starting the engine, to be filled with steam, so as to blow out at the valve all the air that may have previously got into it. The reader is referred to the historical part of this treatise for those parts in the description of Mr Watt's engine, and also to the plates, and their descriptions at the end of the volume.

It must have already occurred to the attentive reader, that such a condenser as has now been described could not act efficiently for any considerable time. On the contrary, it is plain that the jet of water entering the condenser would soon fill it up; and even were this not the case, it is evident that the whole steam which passes through the engine being cooled into water in the condenser, this would accumulate and fill it up. This water must therefore by some expedient be got out of the condenser without admitting the air. Again, it is well known that water usually contains much air mingled with it, or retained in its pores, but which escapes from it when placed in a vacuum. Now, this air would of itself rapidly accumulate in such quantity as to fill up the vacuum of the condenser, and render it inefficient. Such air must therefore be removed out of the condenser, along with the accumulations of injection water, and the condensed water of the steam; and therefore an air-pump is provided, capable of removing both air and water. This air-pump is placed beside the condenser in the cold well; communicating with it by a foot-valve, which permits the air and water to go out and prevents their return; and delivering that air and water which it removes into another smaller reservoir, named the hot well, from the circumstance that the water withdrawn from the engine has been made warm by mixing with and condensing the hot steam, which it does not generally cool below 80° or 90° F.

These appendages of the condenser, the cold well, the injection-pipe, the air-pump, the hot well, the blow-through valve, the foot-valve, the delivering valvé, &c., are represented in fig. 187, in a usual arrangement.

Fig. 187.



a is the cylinder, *b* the eduction-pipe, *c* the condenser, *h* the blow-through valve, *g* the injection cock and pipe, *k* the foot-valve, *d* the air-pump, *e* the hot well, *f* the cold water pump, to supply the cold well continually with water, when that cannot come directly from a spring or stream sufficiently high.

The reader will find other arrangements of these parts in the plates and their descriptions. The air-pump is generally worked by the great beam of the steam-engine, as in the figure, and it has about half the area and half the stroke of the cylinder of the engine.

Dry condensation is a subject which has attracted much attention from machinists; that is to say, it has been considered very desirable to condense the steam without injecting water amongst it. Mr Watt originally condensed in this manner. He merely placed upright pipes among cold water, and letting the steam into them, allowed it to be condensed by simply coming in contact with the inside of these tubes, which thus formed a condenser. The introduction of a jet of cold water was thus avoided, as also any air it might contain, and thus the air-pump had its duties much diminished. But the efficiency of the engine was found to be very materially impaired; for the instantaneous annihilation of the steam was not effected, in this process of mere surface condensation, in the efficient way in which it had been by the old system of a jet of water.

ON ROTATORY STEAM-ENGINES.

The steam-engine being now most generally used in our workshops, our manufactories, our steam-ships, and our locomotive engines, for *turning round* certain axles or wheels with a continuous whirling or revolving motion, it has therefore appeared to many, the simplest, the most elementary, and the most appropriate manner of applying the moving power, that the steam should itself follow the wheel which it turns, round the circumference of its circle of gyration, and so it is supposed, that by acting immediately and directly on the wheel to be turned round, it should produce the most powerful effect. In this way the action of the steam would be made to resemble the turning of a mill-wheel by the action of the water on the buckets of its rim; and the arrangements by which such an elementary mode of action might be brought about, form what is called a ROTATORY STEAM-ENGINE.

That simplicity of form and of outline are essential to simplicity of action, and to excellence of mechanical action, is a fallacy; that simplicity of figure and fewness of parts are objects of higher importance in machinery than durability, precision, and economy of operation, is a fallacy; that such an elementary machine, if constructed, could give forth any more of that power than is now rendered effective by the common steam-engine in every-day use, is a fallacy, arising in ignorance, ending in disappointment.

We have to state with regret, that very injurious consequences have arisen from this popular error. Many men of high talent and inventive genius have sacrificed their talents, their industry, their lives, to this delusion. The patent-offices of England, Scotland, Ireland, and France and America, the mechanical periodicals of them all, the transactions of societies for promoting the arts, the "machines approuvées par l'Académie," the journal of the Franklin Institution, all teem with inventions of rotatory engines, and substitutes for the crank of the common steam-engine, by which power and simplicity are to be united in the highest degree. And yet, when we look around us, we nowhere find that a phalanx of talent thus concentrated with a singleness of purpose, and an indomitable perseverance worthy a more hopeful object, has ever been successful in producing one form of mechanism to stand in competition with the common every-day reciprocating-engine, with its crank and its fly-wheel and all its much condemned appendages. In this country alone a crowd of inventors have not only proceeded so far as to expend their ingenuity, labour, and money, in inventing and constructing machines of this class, and making them the subject of experiment, but more than a hundred of them have actually laid out in succession four or five hundred pounds a-piece in procuring the royal grant of monopoly for their valuable contrivances. We feel it, therefore, to be our duty to give a full and uncompromising exposure of the fallacies of the rotatory engine. We regard such a fallacy as a grievous obstruction to the advancement of the arts and the industry of Great Britain. It is to the prevalence of ignorance on this subject, that much of the misdirection of mechanical talent, in so far as it has been applied to the improvement of our prime movers, is to be attributed. Again and again, year after year, do we find the same machine invented and re-invented, and the same experiments repeated and the identical failures encountered. Of these failures, however, there is only a small number comparatively which comes before the public. Those alone which obtain patents are dragged into light; and of these we are only left to infer the subsequent failure, from the circumstance of discovering that their existence is recognised nowhere except in the parchments of the Patent-Office. It is indeed a matter of general regret, not limited to the subject of rotatory engines, that false pride should prevent men from publishing the results of such experiments as may not be perfectly successful in accomplishing the objects originally intended. It should be recollected, that, as evidence of the truth or falsehood of some great principle, no experiment is valueless, if simply and faithfully described; and that, if it do not serve as a signal-post to point the way to truth, it may at least prove useful as a beacon to warn from the path of error. It is to unsuccessful experiments that we owe many of our most valuable scientific discoveries. The failure of an attempt to make a sucking pump operate when the working bucket was more than 33 feet above the surface of the water, led to an acquaintance with the doctrine of atmospheric pressure, and opened a new field of research to the genius of Galileo, Torricelli, and Boyle; and Sir Humphrey Davy is reported, on an occasion where he was shown a dexterously manipulated experiment, to have exclaimed, "I thank God I was not made a dexterous manipulator, for the most important of my discoveries have been suggested to me by failures." Thus we find that the record of error may often prove a contribution to truth; and the man who is sufficiently unselfish to impart to others the benefit of such experience, is the disinterested friend of science. Had all the failures of the rotatory engine been publicly recorded that avenue of misdirected effort would long ago have been closed.

Our present object is to bring together and place under the eye of the reader, all that has been done upon this subject; the attempts that have been made, and the failures of those attempts. We shall thus show that the attempts at a successful rotatory steam-engine which are every day produced, are mere repetitions of experiments which have long ago been tried in circumstances precisely the same, and have long hopelessly failed and been abandoned: that these attempts were made in circumstances that were well suited to ensure their success, had success been possible. Let it be recollected that the only useful office performed by machinery, is the transmission of power from an animal or element, and never the creation of power. It can modify motion in direction, velocity, and force, so as to expend itself in one manner rather than another, but it can never create motion or generate power. This is true, otherwise all the experience of the laws of matter which has been obtained since the use of inductive philosophy would be false. Solid matter may obey force and modify it, but can never create power. The only enquiry to be made, therefore, in regard to any engine in this: when the force of steam or any other force is applied to the machine, does it turn all that force to a useful purpose, without further diminution than is occasioned by necessary friction and resistance of the air, and the least possible loss of power by transmission? When steam bursts a boiler, or water overturns the embankment of a reservoir, the powers of heat and of gravity produce their full effect; but it is not a useful effect. The object of a machine is to expend it parsimoniously in rendering the greatest portion of its effect useful. In the case of steam the only question entertained is, which form of engine is best calculated for converting most of that power to a useful purpose?

The common, or reciprocating steam-engine, is distinguished from the rotatory steam-engine by the nature of certain parts of its mechanism, which convey the motion of the steam to the machinery which is to be moved: these are a piston-rod and crank. Now, it is owing to a radical misconception of the nature of this elementary machine, the crank, that innumerable schemes have been devised for the production of circular motion, without the intervention of the crank, either by giving to the steam itself an immediate circular action, or by the substitution of some other less elementary mechanism between the reciprocating piston and the revolving axis, as the means of producing its rotation. In the most common form of the rotatory engine, the cylinder, piston-rod, and cranked axle are superseded by a cylinder, valve, stop, and axis. In the same way as a mill-wheel is compelled to move in a circle, either by the direct action of water or wind upon it, so is the drum, or wheel, the valves, fans, or other projections on its circumference, urged round by the force of the steam, and, enclosed in an outer cylinder, or case, gives revolution to an axis to which it is attached. This direct rotatory action of the steam will, it is imagined, give out the effect of the steam more powerfully, uniformly, and economically, than the common mode of reciprocating action when converted by the crank into revolution.

Rotatory engines may be arranged, according to their manner of action, into four classes:—

1st CLASS—Rotatory engines of simple emission.

2d CLASS—Rotatory engines of medial effect.

3d CLASS—Rotatory engines of hydrostatical reaction.

4th CLASS—Rotatory engines of the revolving piston.

As closely connected with the rotatory engines, in the fallacy which has given rise to most of them, we may add a series of inventions, forming a

5th CLASS—Revolving mechanism substituted for the crank.

CLASS I.—The rotatory engine of simple emission forms the earliest, as well as the most rude and elementary, method of giving motion to mechanism by the escape of vapour or steam. It is described by Hero of Alexandria, in his *Pneumatica*, upwards of 120 years before the Christian era, and depends for its effect upon the same principle which gives to a rocket its career, and makes a fire-wheel revolve in displaying its beautiful lights. In these, as in all instances where fire or steam, or any fluid or gas is generated in a chamber, from which it is permitted to issue with violence, it will, in its exit, drive the vessel from which it issues away from it in the opposite direction; and it is, in fact, merely an application of the principle of recoil, where the gas generated by the explosion of the powder urges the ball outwards in one direction, and forces the breech of the gun backwards in the opposite one. The same recoil is felt in all cases of simple emission of a fluid from a reservoir; and if it be so arranged that water, steam, air, or the gaseous product of gunpowder, rushes out of a chamber through the arms of a revolving wheel, the openings of escape being properly directed, the recoil will urge round the wheel, and we shall have a revolving engine of simple emission. By availing himself of this principle, the machinist of Alexandria produced a working engine, merely by heating a vessel containing water and air, and allowing the vapour to rush from two opposite orifices, at the ends of two arms proceeding from a sphere, which the emission was employed to move.

Instead of using the principle of recoil, the force of steam, issuing with violence as we see it from the mouth of a kettle or boiler, may be directed upon the vanes of a wheel so as to blow them round; and thus we have a second variety in the manner of converting the simple issue of steam into a moving power. This second species of the rotatory steam-engine of simple emission has been already noticed; it was invented by Branca in 1629. Since that time the engines of this class have been frequently re-invented and slightly modified.

The theory of machines of simple emission has been frequently and fully investigated; and the result is, that there is no possibility of obtaining by simple emission, in the most favourable circumstances imaginable, more than half the power of the steam, so as to make it available to any useful mechanical effect. The other half is wasted in giving off its impulsion to the air, or is expended in a current equally unavailing. Practical experience corroborates the predictions of theory. Smeaton and Pelectan have made the machine of simple issue the subject of careful experiment:—3 parts out of 11, 8 out of 27, and 2 out of 5, are the highest measures of the useful effect that it has yet been found practicable to attain.

Class II.—Rotatory engines of medial effect are those which do not immediately give revolution to an axis, by the action of steam upon the wheel, but have a medium of communication between the power and the effect, which medium is the direct agent in circular motion. This class of engines will be well understood, by taking as its type any simple steam-machine, such as Savery's or Newcomen's, when used for raising water, to turn a common mill-wheel. The engine of Savery raises water by pressing directly on its surface; and it is only necessary to allow this water to fall on a wheel, and it will form an engine of the second class.

A variety of this class has been invented, of which the Fire-wheel of Amontons is a type. The steam pushes water through certain channels that form the arms of the wheel, from a set of chambers on one side of the wheel, to a corresponding set of chambers on the opposite, and thus the side filled with water preponderates over the other, and the wheel revolves. The water being constantly driven off by the steam from a given side of the wheel to that opposite, uniform revolution is the result of the weight of the water. In this case, although steam is the agent, water is the means of communicating the rotatory motion.

Solids have also been made the medium of effecting rotation in this manner. Weights, in the form of pistons, have been transferred by the force of steam to a considerable distance from the centre on one side of a wheel, and drawn nearer to it on the other side, so as, by bringing about a continual preponderance of one side, to effect a revolution. Watt and De Witty have designed arrangements of mechanism of this nature.

In this class of engines the loss of effect is manifest; for it is necessary that the steam, in order to produce the circular motion, shall give out its force in setting the medium, (viz. the reciprocating tackling in the wheel,) in motion, and in overcoming the very great resistance of the liquid in all the pipes and passages and valves, through which it is transmitted to alternate sides of the wheel in every revolution. The force thus subtracted from useful effect is power lost.

In those which move weights from and towards the circumference, there are mere groups of reciprocating pistons, without cranks, and partaking of the defects to be explained in Class V. In fact, in the engines of Watt and De Witty of this class, we have a number of reciprocating engines ranged round a wheel to do the work of one.

In the case of the fluid medium we have not only a loss of all the power expended in moving the medium itself, but also the additional loss of effect encountered in all modes hitherto adopted for applying a fluid to the rotation of a wheel; a loss, in the best examples ever tried, exceeding the sixth part of the power.

Class III.—Engines of hydrostatical reaction are more effective than either of the former classes. As invented by Watt in 1796, this species of engine consisted of steam-vessels, in the form of hollow rings or circular channels, with proper inlets and outlets for the steam, mounted on horizontal axles, like the wheels and buckets of a water-mill, and wholly immersed in some fluid. These tubular wheels were made of iron, six feet in diameter, and the reaction of mercury was employed to give revolution to them. The engine moved, but was found to be inefficient, and was abandoned, although it had been tried in very favourable circumstances. The principle of action is this. Steam is admitted into a circular channel, or chamber, on the circumference of a wheel. This chamber is partially filled with some liquid; the pressure of the steam is expended in pushing the mercury in one direction, and the end of the chamber in the opposite way; so that, while the liquid is thus forced out of the chamber, the chamber is by an equal force pushed away from the liquid. The wheel is thus moved round. It is apparent that a part of the force is employed in propelling the wheel, and the remainder is expended in overcoming the resistance of the liquid of reaction, and expelling it from the chambers, which remainder is a large portion of the power withdrawn from useful effect.

Class IV.—Rotatory engines of the revolving piston are constructed on a much better principle, and hold out much fairer prospects of successful competition with those of the reciprocating piston, than any of the species of the first three classes that have been already considered. In these classes the steam is not confined in rigid vessels, but its action is expended in producing currents in fluids, and expending motion in medial effects, which are useless. This is not the case in the steam-engine of the revolving piston. The steam is confined in a close and rigid chamber, and acts only on solid inflexible surfaces, and escapes along confined passages, so that its full effect may be obtained in useful work. Abstractly considered, it is an engine capable of giving out the full power of the steam, and, therefore, may fairly be imagined to come into competition with the ordinary reciprocating crank engine. The objections to it are entirely of a practical nature, and regard the engine, not in its abstract mathematical form, but as a machine made of destructible matter—of matter imperfectly elastic—of surfaces offering resistance to motion—of matter obeying the known laws of motion and rest. These objections are not the less valid that they are of a sensible and tangible, rather than a speculative description. But, as a natural consequence of the more plausible deceptions held out by this species than by any of the three preceding ones, it has followed that the fallacies of this class have been more widely seductive than the others; and many eminent mechanicians have been led astray by them. The fallacy of this class of engines we shall expose in conjunction with the next class, as the same misconceptions lie, to a considerable extent, at the root of both.

Class V.—Revolving mechanism substituted for the crank of the common steam-engine, for the purpose of obtaining from the reciprocating piston a rotatory effect otherwise than by the crank, and in a better manner than by the crank, forms a class of inventions involving fallacies similar to those in which the revolving piston has originated. These two may therefore be considered together.

Although the name of Watt has been included in the list of inventors of substitutes for the crank, it should be observed, that he was only driven to the invention of a substitute by the circumstance of a patent having been previously obtained for the crank in its simple form; and that he abandoned his beautiful but more complex mechanism on the instant that the elementary crank was released from the fetters of monopoly. It is due also to his memory to say, that the sun and planet wheel, which he substituted for the crank, is a disguised crank, possessing all the valuable properties, excepting simplicity and smallness of friction, which gave to the crank its present eminence as a mean of obtaining rotatory effect. It is remarkable that the fallacies regarding the now universally employed crank were coëval with the first suggestion for applying it as the vehicle of rotative steam power. John Stewart, in describing his mechanism for this purpose, in the Philosophical Transactions, 1777, observes, that "the crank or winch is a mode of obtaining the circular motion which naturally occurs in theory, but in practice it would be impossible, from the nature of the motion of the engine, which depends on the force of the steam, and cannot be ascertained in its length; and, therefore, on the first variation, the machine would either be broke to pieces or turned back." Mr Smeaton agrees with Mr Stewart on the inapplicability of the crank; but adduces another objection, "That great loss would be incurred by the absolute stop of the whole mass of moving parts as often as the direction of the motion is changed, and that although a heavy fly-wheel might be applied to regulate the motion, it would be a great encumbrance to the mill." In such phrase of evil omen was it thus confidently predicted, that the simple means now in every-day use for the communication of steam power to revolving machinery, would either be attended with great loss, be very desultory in its action, or altogether break the machine to pieces. At that time, however, the crank was not in use; but the very same objections are still urged by those who have, every day, before them the practical confutation of their assertions.

I. In the abstract and purely theoretical view of the subject it can be shown that the present mode of applying the steam possesses none of the disadvantages, and that the rotatory mode possesses none of the superiority attributed to it.

In making the comparison between the rotating and reciprocating piston, let it be supposed that the vessels containing the steam are equally rigid, equally perfect in their form, and are equally divested of friction, and that there shall have been obtained for the steam a basis of reaction as satisfactory in the case of the rotatory, as that which the reciprocating engine possesses in the ends of the cylinder; then, upon this hypothetical condition, neither engine will excel the other, each will move over a space with a power and velocity proportioned to the steam which is spent on it, and that engine will do most work which uses the greatest quantity of steam.

The great fundamental principle in the construction of machinery is, that the work depends in quantity only upon the quantity and velocity of the power applied, and not at all upon the form of the machine; in other words, that a machine has no power, either of consuming or creating motive power; that it can only transmit it; that it can only modify it to suit particular purposes; and that what it loses in pressure it will gain in velocity; this is on the supposition, of course, that the machine is perfectly well made, without friction, and without permitting the escape and waste of power in some effect not conducive to the end in view. Setting out, then, from this great mental principle of virtual velocities, we might satisfy ourselves with asserting the truth we now wish to establish as an evident deduction from it, and thence conclude that there is not necessarily any loss of power by the crank steam-engine.

This summary process would not, however, satisfy the enquirer or inventor who has taken the erroneous view of the subject, unless he were given to understand how this great doctrine may be made to bear on the peculiar difficulties of the case. He will return upon us with the question—" How is it that, in the common crank, we are able to show that, at two given points in its revolution, the position is such that an infinite power would produce no effect at all; that there are only two instants of time in which the force and its effect are equal; and that, at every other point, the pressure given out by the steam to the crank is less than the original pressure of the steam on the piston? How is this inconsistency to be reconciled?" We think it right to give a direct answer to this question, because a considerable authority, Mr Tredgold, has made a serious mistake in reporting, and apparently demonstrating, that the rotatory and crank engines actually differ in theory in the proportion of 2 to 3—the proportion being against the rotatory engine; whereas, if they be not equal, our whole system of mechanics since the time of Galileo has been resting on a fallacy.

Let it be recollected, then, that at the two extremes of the line of centres the greatest loss is said to take place. Now, here the fact is, that it is impossible there can be loss of power, for there is no power at all exerted; there is no steam in action: it is forgotten, that, at this point, the communication which supplies the steam from the boiler has been cut off. The steam on one side of the piston having done its work, only waits to be released from the chamber, and escapes on the instant of the opening of the eduction-valve, and at the same instant is in the act of being permitted to enter on the opposite side, for reversing the motion. At these points, therefore, all application of force has ceased, and arrangements are making for reversing the motion; and, as no power is applied, none can be lost.

In regard to the remaining points of the circle, at which it is said that power is lost, it is easy to show that the velocity imparted to the crank is such as to be an exact equivalent to the force which is apparently lost. The following table presents the results of calculations of power and velocity, showing that the relative velocity at a given point in the circle is increased exactly in the same ratio as the force or useful pressure is diminished, so as at all times to present the same dynamical equivalent. The table extends from the one neutral point of the orbit of the crank to the other, comprehending a semicircle divided into ten equal parts. The first column indicates the point in the semicircle at which the force and velocity are estimated; the next column shows the per-centage of the direct force of the steam on the piston, which is given out in useful pressure upon the crank of the engine; and the last column, the relative velocity of the crank at each point.

Place of the crank.	Per-Centage of power given out in pressure.	Relative velocity.
0°	0.00	Infinite.
18	30.90	3.236
36	58.78	1.701

54°	80.90	1.236
72	95.11	1.051
90	100.00	1.000
108	95.11	1.051
126	80.90	1.236
144	58.78	1.701
162	30.90	3.236
180	0.00	Infinite.

From this table, already explained when treating on the crank, it is evident that when we take note, as we must do in every correct estimate of power, both of force and velocity, the crank has at each point the equivalent in greater relative velocity for less force.

The numbers in the second column also represent the velocity of the piston in relation to the crank; so that, when the velocity of the crank is uniform, the velocity of the piston, or the steam consumed, which is proportional to its velocity, is in the exact ratio of the useful pressure on the crank, or that reckoned in the direction of its motion.

The last consideration which we shall submit upon this part of the subject is, that if the average of the useful pressures on the crank be taken for every point of its orbit, it will amount to about 63·3 per cent. for the whole circle. Now, as the circumference of the orbit of the crank is greater than the stroke of the piston in the cylinder, the whole space described in a given time by the crank is greater than the whole space described by the piston, also in the proportion of 3·1416 to 2; so that, if we combine the greater length of the whole orbit with the smaller useful force on it, we shall have an exact equivalent to the greater force on the piston moved through a smaller space.

The error of Mr Tredgold lies, not in his estimate of the effect of the crank, but in his estimate of the effect of the steam in the rotatory engine. By a strange oversight, he gives a statement of its power as much under the truth as that of the crank is generally stated under the truth. We admit that, in the first abstract view of the subject, the rotatory is theoretically a perfectly efficient propagator of power, and we have merely designed to show that in theory the crank has not the faults usually attributed to it, and is also a perfect machine. We shall by and by show what the considerations are by which the impracticability of the rotatory scheme is exposed.

It appears, therefore, that the power of steam is by no means disadvantageously applied through the medium of the crank in the ordinary way; because, 1. the relative velocity of the crank is in the inverse ratio of the useful pressure upon it; 2. because the average of useful pressure on the crank during the whole revolution is less than the pressure on the piston, only in the proportion in which the whole space moved over by the latter is less than the space described by the former, so that the whole effect is equal to the whole power; 3. because the steam is not at all expended at the neutral points, and because its expenditure is at every point exactly proportioned to the pressure which it gives out, the velocity of the piston being in that ratio. In theory, therefore, the ordinary crank possesses no inferiority to the rotatory machine, as an engine for applying the power of steam to revolving machinery.

II. In a practical point of view, it may be shown, that the rotatory steam-engines are as yet greatly inferior to the common reciprocating crank-engine in simplicity of parts, easy construction, cheapness, amount of friction, compactness, precision and uniformity of work, and durability and economy in use; and that they do not possess any of the peculiar applicability that has been attributed to them, to the great purposes of inland navigation and railway transport.

1. Simplicity.—A little unfairness is sometimes inadvertently used by inventors of rotatory engines, in making comparisons with their machines and the common crank engine; they select the large beam-engine with all its conveniences and appendages, and compare it with the simplest form of the rotatory engine; but in justice we may be allowed to take the simplest form of both. Now, there is a simple form of engine used both in America and in this country, of the oscillating species as it is called, and this species of reciprocating engine consists only of the following parts:—cylinder, piston, and cranked axle; there are no valves or further mechanism of any kind, so that where simplicity is the first great requisite, this kind may be used with advantage. The rotatory engine of the most simple species must have its drum, diaphragm, piston, and axle.

If we take those forms of the rotatory engine which require valve-gear, air-pump, condenser, force-pumps, &c., such appendages will have no advantage of any kind, in either form; but in working the pumps which are themselves reciprocating, the reciprocating engine will have the advantage of more direct, immediate, and simple action; for in the rotatory engine additional mechanism is necessary to convert the revolving motion into one calculated for reciprocating pumps.*

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* But since in reciprocating engines, the beams seem to be gradually going out of use, they will at length cease to have any advantage over the rotatory sort on the score of beams. It is for this reason that some similar objections, repeated and urged at greater length a little farther on in the former edition, are now omitted.

2. In ease of construction the simple form of reciprocating engines incomparably excels the rotatory. To possess equal powers, the rotatory drum would require to be of much larger diameter than the reciprocating cylinder; and the difficulty of construction increases in a high ratio with the diameter. The diaphragm is also a sliding or revolving piece of mechanism, whose rubbing surfaces require the greatest precision of workmanship. The revolving piston is also a practical problem of the greatest difficulty, and one which has never been satisfactorily solved; for if it be rectangular with plane surfaces, it is scarcely possible to make its surfaces steam-tight; and if it be a circular and revolving piston, its surface and that of the drum become surfaces of double curvature, and the difficulty is then prodigiously increased. The metallic piston of the common steam-engine is the most perfect and most simple piece of mechanism, which can be made by a very ordinary workman, and which, if imperfectly fitted, will, in the progress of doing its work, become of itself every day more and more perfect. An editor of a well-known practical journal, although an advocate for the rotatory engine, speaking of one of its simplest forms, is compelled to admit, "that there being no mode described of making the parts of the engine steam-tight by packing, they must be all made so by accurate workmanship and grinding, the expense of which, in the outset and in repairs, would certainly be too considerable to allow it to come into competition with other steam-engines of a more common and practicable construction." His admission is equally applicable and fatal to all the forms of the engine.

3. The cheapness and first cost of the engine will result from the two former points of inferiority, and will be

further shown, from those which follow, to be greatly and necessarily in favour of the common engine. Not only are the parts, from their nature, more easy of construction, but the extent of polished surface will be shown to be much greater in the rotatory, than in the reciprocating engine.

4. The quantity of surface exposed to friction is greater in the rotatory engine. Let it be recollected that, in the rotatory engine, the piston describes the semi-circumference of the circle, while the piston of the reciprocating engine is describing the diameter of it. Let it also be recollected, that the reciprocating piston passes back through the returning stroke, over the very same surface through which it formerly descended, while the rotatory piston necessarily revolves over a new surface, forming the other semi-circumference of its orbit. Let it also be recollected, that the form of the reciprocating cylinder may be so proportioned, that it may have a minimum of surface, while the length of the circuit of the rotatory piston prevents the possibility of giving it a proportion to the radius of the piston by which this object would be attained; for it would be equivalent to making a circle whose diameter should be equal to its circumference, which is impossible. It is impossible, therefore, that the friction can ever be as small in the rotatory as in the reciprocating engine.

5. Compactness.—It follows in like manner, that the bulk and space occupied by the rotatory engine must be greater than in the reciprocating engine; for in the one case the piston must describe the circumference of a circle, whose diameter is greater than twice the radius of the piston, and in the other case it is only necessary that the piston pass through the diameter of it.

6. In precision and uniformity of working, its inferiority will be rendered manifest under head III., when the peculiarities of the crank are explained.

7. In durability and economy in the wear and tear of ordinary working, the rotatory must, from certain elements in its constitution, be necessarily far inferior to the common engine. It contains in the very nature of its action, elements of speedy destruction and expensive and frequent repairs, so that it can never become an economical engine. Before proceeding, however, to demonstrate the cause of this inferiority, the fact of this inferiority as existing in all previous engines, we shall adduce from the unwilling evidence of a friend to rotatory engines. Speaking of Mr Halliday's engine, he says that "the extreme accuracy and nice fitting of parts necessary for it, will make it very difficult to execute and very easily deranged. Rotatory steam-engines possess considerable advantages both as to speed and economy of power, and would therefore be preferable if they could be made to work as well for a continuance, and be as easily kept in good order as common alternating steam-engines; but from their being so very seldom used, we apprehend that this is very far from being the case with any of them at present, and that the production of a rotatory steam-engine possessed of these necessary qualities, is still an object of research." So far the Editor of the Repertory of Arts, in testimony that the rotatory steam-engine *never has* been made to work durably and economically; we now go on to show the reason.

It is essential to the durability of a machine that its parts should wear uniformly, and that, if possible, the mere process of wearing should make them fit each other more closely. This is pre-eminently true of the piston and cylinder of a common reciprocating steam-engine. Its piston, cylinder, and valves fit more closely as they wear, and are worn with perfect uniformity, so as not to require repair, until, by long working, the whole thickness of matter in action shall at length have been consumed. This is the perfection of mechanism, and is admirably exemplified in the metallic piston of a steam-engine, which, working night and day, will require no repair of any kind, until, after a long period of years, the whole strength of the metallic rings shall have been consumed.

In the rotatory piston, this uniformity of friction, this increasing adaptation of surfaces, this permanence of the best working condition, has not been attained. A common reciprocating steam-engine attains its best working condition after it has wrought for some years; but a rotatory steam-engine, if it have been brought by care and precision in workmanship to a state of high finish and perfect accuracy, so as to work well for a day, commences from that moment a course of deterioration, every succeeding degree of which accelerates the progress of decay; a decay which has as yet only been retarded by continual, laborious, and expensive repairs. The following considerations may illustrate this.

Suppose two perfectly flat plates of polished metal perfectly round to be laid one upon the other, so as exactly to coincide at every point; let the undermost rest upon a table, and let the uppermost be so made as to turn round on an axis while in contact with the other, and let a rapid motion be communicated to the uppermost: let us consider what the result of the attrition of one of these upon the other will be: will they wear equally, so as to remain in a state of mutual adaptation, or will they not? Experience furnishes us with a reply that exactly quadrates with a reasonable expectation: they will not wear equally, they will not retain their form, they will not remain flat: they will wear away most rapidly at the circumference, and wear open there while they are quite close at the centre. This is principally owing to the want of perfect steadiness in the centres or axles, which allows the one surface in some degree to rock or oscillate on the other; and thus the parts more remote from the centre have an opportunity of alternately meeting and separating whilst revolving, and consequently, of wearing each other beyond where they meet when at rest.* This circumstance has caused the failure of many beautiful inventions. It is one of the reasons why conical bearings have been abandoned for cylindrical ones; and it is the reason why a most beautiful class of inventions has been totally useless to the improvement of the common steam-engine; we refer to the revolving valves invented by Oliver Evans and by Murray, but now abandoned, in spite of their simplicity and original cheapness, on account of this inequality in the attrition of flat surfaces revolving round a centre.

The application of the result of this illustrative experiment to the subject in question, is abundantly obvious, The rotatory piston is necessarily and inevitably of this nature. Performing a circuit round a centre, different portions of the bearing surfaces subjected to pressure, and necessarily in contact, and requiring to be steam-tight, revolve at unequal distances from the centre; hence, owing to the want of perfect steadiness in the axles, whether arising from looseness or yielding of the parts, the circumferential surfaces wear more rapidly, and become unfit for use long before the central parts have suffered any sensible effect. It is this unsteadiness which renders it impossible to keep some rotatory engines in a working condition with advantage; and hence each day's work renders them less fit for the duty of the next.

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* This has been sometimes, although very improperly, ascribed solely to the greater velocity of the parts which are more remote from the centre, occasioning more rapid wear. But on no such hypothesis alone can it be explained. For if the central parts are really keeping the parts separate which are more remote from the centre, then the parts only that are in contact would wear, which would allow the rest gradually to become close. Thus the evil would effectually cure itself, without any regard to distance from the centre. Indeed nothing like any satisfactory reason has ever been given why two spherical surfaces, a hollow and a round, might not continue to work perfectly tight,

8. The peculiar applicability of the rotatory form to steam navigation and land locomotion has been much insisted on by projectors of rotatory engines. In a steam-vessel, it is first of all desirable to have the axis of the paddles as high as possible, and the weight of the engine as low as possible. Now if the engine be placed on the axis of the wheels, one of two evils is incurred; either the axis of the wheels must be brought low, which impairs the action of the paddles, or the weight of the engines must be raised, rendering the vessel top-heavy, unsteady, or, as it is technically called, "crank," and liable to be upset. By the ordinary engine, the axis is elevated to or above the deck, while the weight of the engine remains on the floor, at the bottom of the vessel. Again, to the application of the rotatory steam-engine to terrestrial locomotion there are similar objections. If the rotatory engine is placed immediately upon the axle of the propelling wheels, there can be no springs between it and the wheels, so that every jolt would derange the machinery. The weight of the engine if placed on the axle would in turn reciprocate the evil by

knocking the wheels in pieces. In the reciprocating engine, these evils are prevented by the detachment of the engine from the axle, and the propagation of power through rods, wheels, or chains, to the propelling wheel or axis; and if any fault still remain in the principle of locomotive engines, it is the want of perfect detachment in the very respect which the introduction of the rotatory engine would render so difficult.

All these considerations, of a most important and immediate practical bearing, clearly prove, that although, in the most abstract and elementary theoretical view of the subject, there be an apparent equality of effect in the rotatory and the reciprocating steam-engines, yet there are practical objections to rotatory engines which have not yet been overcome.

III. It is lastly our duty to show that the common reciprocating crank steam-engine, not only does not possess the disadvantages attributed to it, but that it possesses certain very peculiar properties which may not have been hitherto clearly understood and defined, but which nevertheless do adapt it in so admirable a manner to the nature of steam and of solid matter, and to the necessary imperfections of all human mechanism, as to have rendered it triumphant in universal practice over every competitor.

1. It was long imagined that the transmission of power through a *crank*, or *bend*, or *handle* in an axle, was attended in the steam-engine with great loss of effect. In the opinion of such men as Smeaton, the crank was never likely to be used as the means of obtaining rotatory motion from steam; while it is this very crank that is, in our day, used alone and universally over all other methods, although a great variety of other methods have been successively in-

vented, and finally abandoned for the simple elementary crank. Yet it is not without some show of reason, that objections have been made against the practical working of the crank. We admit that the argument was rather a staggering one, but the difficulty has lately been wholly removed.

The staggering fact to which we refer was this: it is given as stated by Dr Penneck of Penzance, Cornwall, in describing a substitute proposed by him for the crank. "Some have considered a wheel as one-third more powerful than the crank, and others that no power is lost by the crank; but, confining myself to *practical results*, it appears from the report of the duty of steam-engines, as done in Cornwall, and published by the Messrs Lean, that the performance of the crank engines bears no proportion to those in which no crank is employed." He then proceeds to show the advantages of his own engine, in which a ratchet-wheel is moved by an arm, always acting at the extremity of a radius, by which means he hopes to save the loss of power occasioned by the crank. The fact related by Dr Penneck was perfectly accurate. It had happened that the crank steam-engines, working expansively in Cornwall, had never given out an adequate effect. That the fault did not lie in the crank, but in other parts of the arrangement, is now apparent: it consisted in the want of proper adjustments to admit of favourable action in using the steam expansively. Arrangements for this purpose have, however, been at length accomplished, and crank engines are now in Cornwall doing the same work as the average of those that have no crank. We have before us indications of the *actual pressure of the steam on the cylinder*, as obtained by a very accurate indicator, applied by Mr Smith for Mr Fairbairn of Manchester, who visited the mines for that purpose, and has been kind enough to favour us with a copy of his diagrams and observations.* We have thus the means of comparing the power actually exerted on the piston with the work done, and find the result of the comparison to be, that *the work done is within ten per cent. of being perfectly equal to the power employed.* Here, then, we arrive at this conclusion, that the utmost reach of improvement in the mechanism of the steam-engine, if it even attained to perfection, would not save more than a few per cents. That the crank-engine is, therefore, as at present used, as near in practice to the perfection of mechanism as anything we can hope to obtain, is, we think, satisfactorily explained.

2. The crank, as a means of converting the reciprocation of the piston of a steam-engine into continuous revolving movement, possesses certain singular and beautiful properties which distinguish it from every other means of producing that conversion, and which appear to be so perfectly adapted to the nature of steam and the constitution of solid matter, that we are indebted to it materially, though indirectly, for the very great advantages which we derive from the modern steam-engine as a source of mechanical power. Let us examine into the causes of this well-established practical superiority of the crank to all other modes of producing revolving motion. Let it be observed, that in the reciprocating piston, from which the crank derives its motion, the following things take place: the piston is to be put in motion in one direction, then

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* The results of extensive and accurate experiments on the Cornish engines, by a Committee of the British Association, are given in their Reports for 1843, 1844.

stopped, then put in motion in the opposite direction, stopped again, and then its motion resumed in the first direction. We shall see how admirably the crank adapts itself to these changes; so that, while the piston with which it is rigidly connected takes every velocity between its maximum velocity and perfect rest, the crank goes forward with a motion perfectly regular and perfectly unimpeded. The necessity of this gradual change from motion to rest, and a reverse direction of motion, is obvious. Matter in motion acquires momentum and cannot be stopped, but its impetus must be equally and gradually removed, otherwise these moving parts are subjected to concussion as if by the stroke of a hammer, and must either suffer injury or produce it; for, when in motion, matter requires a force to stop it equal to the force which gave it that motion. And, on the other hand, when brought to rest, matter cannot instantly be set in motion in the opposite direction without a stroke and concussion equally violent. To work smoothly, durably, profitably, and uniformly, matter must be put in motion by gentle gradations, beginning with a very gentle velocity, and gradually increasing in velocity like a body set in motion down an inclined plane, where, if it move one foot in the first second, it moves three in the next, five in the next, seven in the next, and so on; and in like manner in coming to rest, it must do so in the same gradual way in which an arrow shot from a bow vertically into the air loses its motion; for in the end of its course it moves seven feet in the first quarter of the last second of time, five feet in the next quarter of a second, three feet in the next, and only one foot in the last, and then subsides into rest at the instant before it recommences motion downwards, which it does in a manner perfectly similar. It is required, therefore, that while the motion which the steam gives off by the crank be uniform and continuous, the parts of the engine itself shall be allowed time to be alternately brought into a state of rest, without shock, concussion, or jolt, and equally, gradually, and gently be again urged to their greatest velocity in the opposite direction. All this the crank effects with the most exquisite nicety of adjustment; it stops the piston when in motion as gently and softly as if a cushion of eider were placed to receive it: and after having brought it to rest, again begins and accelerates its motion, as gradually and gently, to the highest velocity in the opposite direction. An adjustment so perfect is only possible in such a relation as that which subsists between the circle of the crank and the axis of the piston. Now if we compare this mode of action with any of the substitutes for the crank, by which it has been proposed to gain uniformity of power, we shall find that in these it would be required that the transitions from rest to motion and from motion to rest should be instantaneous; and hence such arrangements, being soon disordered, have been abandoned. It will also be found that in rotatory engines it is necessary that the transitions and changes of arrangement, where these exist, are necessarily instantaneous, or if not, that steam is lost, or that the boasted uniformity of power is sacrificed.

3. The next property of the crank, as an elementary machine for the conversion of motion, is its remarkable power of reducing errors of construction, arrangement, and execution. It is one of the highest recommendations of a piece of mechanism, that any trivial errors committed in its construction shall not materially injure its efficiency; and that any slight derangement in its adjustment shall

not be attended with immediate deterioration or aggravated injury; but that, on the other hand, the efficiency of the machine shall be consistent with such degrees of correctness in workmanship, and accuracy in adjustment, and care in using it, as are consistent with the usual amount of intelligence and attention of ordinary workmen; and that the progress of derangement and necessary tear and wear shall be so gradual as to give timely warning of danger, and admit of ready repair and re-adjustment. The crank is precisely such a piece of mechanism. Errors in the construction or adjustment of valves and other vital mechanism are diminished in effect by the crank one-hundred-fold; the changes of the valves, the essential part of the mechanism, take place only at the top and bottom of the stroke. Now at these instants the crank is on the "line of the centres," as it is technically called; and it is just in this position that a minimum of force is made to act on the crank; so that if the valves do not open with perfect precision, but either a little too soon, or a little too late, then will such error at that part of the circuit be of comparatively trifling consequence, because then the motion of the piston is so slight, that through an arc of twenty degrees of the crank it does not describe the hundredth part of that space; and the effect of any error committed within that range will not affect the result in the crank by one-hundredth part of its full amount.

In like manner, errors in management and errors arising from wearing, are reduced a hundred-fold in effect by transmission through the crank. It has frequently been to us matter of astonishment, to see at the mouths of coal-pits, mines, and quarries, mere remnants of engines, frail rusty old fragments of iron and wood, so loose as scarcely to stand upright upon their bases, to see these superannuated drudges performing heavy work to a very large per-centage of their full power.

4. To these circumstances we may add, that it is to the possession of these properties that we may attribute the fact, that reciprocating engines are constructed of enormous weight in their moving parts, and of ponderous dimensions, without being thereby sensibly deteriorated in working. The crank is but slowly accelerated at the commencement of the stroke, and an accelerated motion is thereby acquired in a manner equally gradual by all parts of the machine; and in like manner, at the termination of the stroke, it brings them to rest in a gradation so gentle and uniformly retarded, as again to receive from them much of the impetus which it had formerly communicated. The impetus, therefore, given to the reciprocating parts is only *lent*, not *lost*.

We have thus endeavoured to expose the nature of the fallacy under which they labour who imagine that the present steam-engine, as derived from Watt, is a machine which destroys or absorbs a large portion of the power it is designed to transmit, and who look to the rotatory engine as a means of increasing the amount of the power given out in useful effect. That the rotatory engines which appear day after day are not new, we show from the fact, that the five great classes which comprehend them all have already been invented and re-invented by upwards of a hundred individuals. That their inventions have been unsuccessful, is manifest from the non-existence of their machines in the daily use of ordinary manufactures. That the failures of these contrivances did not arise from defects accidental to the peculiar arrangements and contrivances of the engine, is rendered probable by the great variety of forms in which they have been re-invented, tried, and abandoned. That they have not failed from deficiencies in the workmanship and practical details, is rendered still more probable by the circumstance of finding among the names of inventors those of the most eminent practical engineers. We have next shown, that in theory, the crank of the steam-engine in common use cannot, as has been supposed, be attended with a loss of power, as such loss would oppose the established doctrine of virtual velocities. It is also shown, from very simple and elementary considerations, that what appears to be lost in force is resumed in velocity; that in proportion as the mean force on the piston is greater than the mean force on the crank, in that proportion is the space described by the latter greater than the space described by the former; that the dynamical effect produced in a given time, is exactly in the proportion of the steam expended in that given time. And thus have we arrived at the conclusion, that the common reciprocating crank steam-engine has not the faults attributed to it in some unsound theories, and which the rotatory engines have been designed to remedy. We have next taken the practical view of the subject. In simplicity of parts, the rotatory engine has no advantage over the reciprocating piston; in difficulty of construction, the rotatory piston far exceeds the reciprocating engine: it is more expensive at the outset—it has more friction—it is more bulky and less compact—it is inferior in precision and uniformity of action to the crank-engine—and there is a peculiarity inherent in the very nature of rotatory mechanism, owing to which the rotatory engine has never yet been rendered either an economical or a durable machine. We have further shown, that even if the rotatory engine could be made economical and durable, its very nature renders it unsuited to the great purposes of steam navigation and inland locomotion: objects to which it has been considered peculiarly applicable. We deemed it an appropriate and instructive conclusion to our enquiry, to examine into the action of the crank, for the purpose of discovering what those remarkable qualities are, which have given to the crank of the common steam-engine its unrivalled superiority as an element for the production of circular motion, and a degree of perfection unattainable by any other mechanism. We have seen that well constructed crank steam-engines are daily performing duty which is within ten per cent. of the theoretical maximum of possible effect—of absolute perfection; that this practical perfection arises from the simplicity of the crank, from its wonderful adaptation to the nature and laws of matter, and of circular motion in connection with rectilineal motion—from its reduction of errors either in construction, adjustment, or management, so as to work well without the absolute necessity of greater intelligence, expertness, and precision, than belong to ordinary workmen—and from the compensating nature of the arrangement of its structure, by which it is accommodated in a remarkable degree to the necessary imperfections of all human mechanism.

ON STEAM-ENGINE BOILERS.

The construction of a boiler may appear so simple an arrangement of materials, as to require very little ingenuity or contrivance; a large enough boiler placed upon a large enough fire being sufficient to generate any requisite supply of steam. Simple, however, as such an arrangement may seem, the best construction of boiler is a subject upon which very widely different and even opposite opinions are entertained by men of the greatest science and experience. There is perhaps no branch of practical art in which so much remains to be determined and improved, and scarcely any which science has done so little to advance. To follow servilely what has, in a given instance, been "found to answer," is the rule of the most sagacious mechanics, and the doctrine of the wisest authors. Those who have attempted to invent have commonly erred; those who have generalized have invariably been rash and unsuccessful, and their erroneous theories have led astray their followers, when they happen to have any.

The art of constructing steam-boilors is, we have said, in its infancy; but it is likely, we think, to make rapid progress. The construction of the bolier of the locomotive-engine, which every day performs what at a former period we should have termed impossibilities, exhibited a strikingly anomalous phenomenon, by which the attention of all men who thought upon such subjects was suddenly arrested: this little barrel of water generates as much steam in an hour, as would formerly have been raised from a boiler and fire occupying a considerable house. The frequent explosion of boilers, both here and in America, has also directed attention to the efficient construction of boilers. The patient experimental enquiry that has since been set on foot, must lay open the whole of the important parts of the question so thoroughly, and bring out the facts with such clearness and precision, as to lead, by safe and rapid induction, to the general principles by which we may be able to predict the result of every supposed case, and deduce safe rules for the guidance of practical men in all circumstances. The investigation of the whole subject of steam-boilers, recently undertaken in America by the Franklin Institute, has already done much to settle many points of dispute. The publication of the reports of the American and English Governments on the explosions of steam-boilers, has elicited many valuable contributions to the stock of knowledge; the useful practical treatise of Mr Armstrong has given us an instructive view of the state of practice in the busy district of Lancashire; the treatises of Mr Wood and M. de Pambour on Railway Locomotives; and the papers, in the Transactions of the Institution of Civil Engineers, on the statistics of Boilers and Combustion, have supplied and discussed a large collection of important facts, that will materially assist the future investigation of the best construction of steam-boilers.

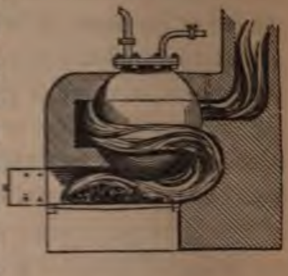
During the first period of the history of the steam-engine, the danger of bursting the boiler, and the difficulty of making it strong enough to resist the internal force acting towards explosion, and also of making the joints tight against the leakage of highly elastic steam, formed the chief obstacles to the introduction of steam as a mechanical mover.

The first important point in preparing a steam-boiler is to secure strength, without unnecessary expense. If we take the simplest form of vessel: suppose a small rectangular water-tank made of sheet-iron, and soldered at the edges, so as to form an air-tight box; then, by simply blowing into it, we shall manifest its weakness; for the sides will first of all bulge out, and, if the materials yield and allow the vessel to change its shape, it will at last swell into a globular form, with angular knobs upon it at the corners, from which pyramidal extremities, the globular parts, will finally be torn away with an explosion, which will, in all probability, take place long before the vessel has attained the shape mentioned above.

The globular or spherical shape was very early adopted, as one of greatest capacity, as a shape in which, the pressure at every point being equal, there remained no force tending to produce flexure, or destroy the equilibrium of strength and strain at any point. A fire was lighted below the boiler, and the steam confined until the heat had raised it to the required pressure. This form was accordingly adopted by Hero, Savery, and others, as noticed in the historical portion of this treatise.

It was soon found that a spherical boiler, when set upon an open fire, required an enormous consumption of fuel to raise a small quantity of steam, the heat being copiously communicated not only to the water in the boiler, but also in very great quantity to the surrounding objects, besides being rapidly carried off by the air. To surround the spherical boiler with non-conducting substances, and to keep the flame throughout its whole extent in contact with the boiler, so as to prevent radiation to surrounding objects, and also to diminish the size of the fire by making it wind round the boiler, were the first steps towards improvement; and we accordingly find in the work of Dr Desaguliers the following form of a boiler. Fig. 188 is a front view of it *set* in a building of brick, which is good as a non-conductor of heat, and can withstand

Fig. 188.



the action of fire. A deep *ash-pit* lies under the fire which rests on parallel iron *bars*, and the *door of the furnace* being kept closed, except when fuel is to be added, the whole of the fuel is in this way supplied with air which passes up between the bars. The flame after having passed along the bottom of the boiler, winds in a corkscrew form around its sides, in a spiral channel formed by the bricks, and called a *flue*, by which the smoke and hot air are conveyed into a *chimney*. A *damper*, as it is called, is formed by a small plate of iron, admitted through a slit where the flue joins the chimney; so that, by pushing in this plate across the flue, the passage of the smoke into the chimney, and consequently of the fresh air into the fire, may be obstructed, the combustion of the fuel retarded, and the too rapid generation of steam prevented. In this simple way, the attendant is enabled, by merely pushing in or drawing out the damper, to regulate with great precision the generation of the steam. The pipe which conducts the steam to the cylinder is called the *steam-pipe;* and there is another called a *feed-pipe*, through which water is supplied to the boiler, as it is continually boiling off in the shape of steam, an inch of water is required for every foot of steam, or six gallons of water for every horse power.

The form next in simplicity to the spherical boiler is the cylindrical. From the facility with which a cylinder is made, it was introduced at a very early period. It stood upright like a bottle as in fig. 189, the fire being placed at the bottom, and the flue winding round that part of the sides covered with water. This form of boiler was found, however, to be weak in the bottom part.

Fig. 189.

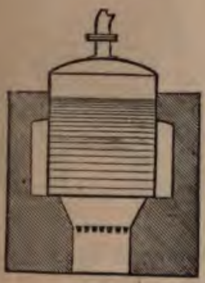
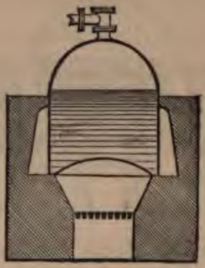


Fig. 190.



For the prevention of these two evils, the cylindrical form of boiler was very soon modified and improved by two opposite expedients, one applied at the top, and the other at the bottom of the cylinder. The top being made hemispherical, possessed all the advantages of a spherical boiler; and the bottom being arched upwards, so as to present a large concave dome to the impact of the flame, this dome being sustained by the cylindrical belt round its spring, a very strong and extensive surface was obtained, as in fig. 190.

In this cylindro-spherical boiler, it was found that the action of the flame on the upright round sides produced but a very slight effect in raising heat. It was therefore desirable that the flame should be brought somewhat under the sides, by inclining them a little outwards. From the form the boiler then assumed, and which has since become very common, it has not inaptly been named the hay-stack boiler, fig. 191.

The same effect was next obtained in many of the boilers of Newcomen, in the way represented in fig. 192,

Fig. 191.

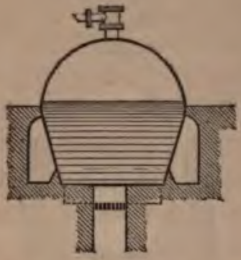
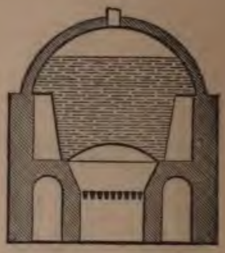


Fig. 192.



so that the flame in the flues impinged upon a surface directly over them; the flues in this case forming a recess in the sides of the boiler, instead of being built around it by the brickwork alone. In process of time, boilers of much larger size came to be required, and the spherical shape was found cumbrous and too capacious, that is to say, contained an enormous mass of water, which it required much time and fuel to heat to the boiling point before any steam could be raised. The diameter, also, of the boiler was so great when much steam was required, that the enormous dome became weakened. To make a stronger boiler, and one which should, at the same time, cover a large fire, the *waggon boiler*, so named from its form, was introduced by Mr Watt. It closely resembles those long, heavily laden, four-wheeled waggons, which a team of six or eight horses may occasionally be seen dragging along with difficulty.

The waggon boiler is made of considerable length, and its transverse section, fig. 193, resembles that of the old cylindrical boiler.

In this form the boiler was long made by Messrs Boulton and Watt. It was afterwards improved by hollowing the sides, in order to bring them more immediately over the flame. Of this form of the waggon boiler, which is much used at present, fig. 194 exhibits a transverse, and fig. 195 a longitudinal section. These forms of boiler, although very convenient, are weak: they are very different from the spherical or cylindro-spherical boilers in strength and safety. The metal of which they consist is not in the form that will resist, to the utmost of its tensile force, a change of shape; but, on the contrary, a very small pressure has been found sufficient to bulge these boilers down towards the fire, and outwards at the sides.

Fig. 193.

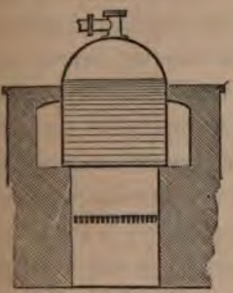


Fig. 194.

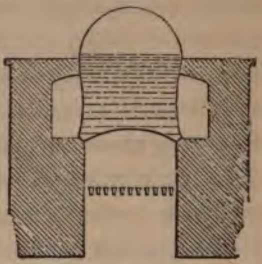
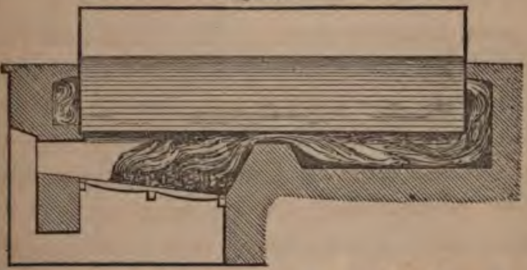


Fig. 195.



From this circumstance, it has been found necessary to place in them strong iron stays, to connect a part of the surface of the boiler having a tendency to bulge out in one direction, with a similar portion of surface having a tendency to bulge out in the opposite direction; so that this tie-bar being stretched in opposite ways, is made to resist, by its tensile force, the outward or bursting pressure. These stays are essential to strength and security in boilers having large surfaces, concave outwardly, or perfectly flat. Their application to the forms of boilers which we have just described is seen in figs. 196, 197, and 198. To avoid the use of stays, and to secure great strength without any other metal than the shell of the boiler itself, is the object of that construction of cylindric boiler now much in use, especially where considerable pressure is used. It is certainly one of the cheapest, safest, and best boilers. A cylinder, figs. 199 and 200, perhaps thirty feet in length and four feet in diameter, with two hemispherical ends, is laid with its axis nearly horizontal; and below it, at one end, is placed the fire, enclosed by brick, as usual. The flame traverses the

Fig. 196.

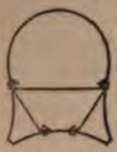


Fig. 197.

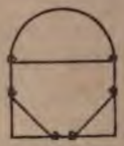


Fig. 198.

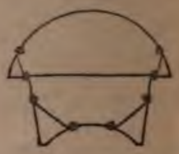


Fig. 199.

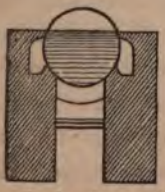
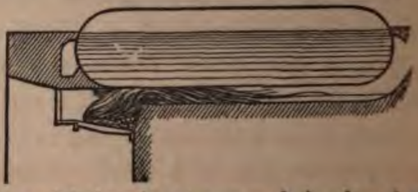


Fig. 200.



bottom of the boiler, beating directly upon its under horizontal surface till it reaches the end furthest from the fire. The flame and hot air then return along the one side of the cylinder, being confined in a brick flue, and, passing along in front of the end which is over the fire, traverses the other side towards the chimney, which it enters after having thus traversed the length of the boiler three times, and applied its heat successively to every point of the cylinder which is covered with water. This is a boiler that requires no stays, and is valuable where room is not important. It contains much water, requires much heat to raise its temperature after being cooled at night, and is very bulky. The Americans have adopted this boiler to a great extent. It was introduced among them by the ingenious Evans. It is generally of a smaller diameter than three feet, and has flat cast-iron ends of great thickness, which they call heads.

The spherical, cylindrical, and waggon shaped, may properly be denominated the simple boilers. But some hundred kinds of boilers have been invented for different purposes; almost all of them designed to save either bulk, weight, or fuel. Some of these have been much more successful than others; and it is necessary to examine upon what principles any improvements attempted in boilers should proceed. In steam navigation, as also in locomotive engines on land, diminished bulk, weight, and consumption of fuel, are all objects of the first importance.

To make a little boiler generate a great deal of steam in a very short time, is a very difficult matter. Let any one take a common open caldron, or boiler, such as is used to boil a few gallons of water; suppose the vessel to hold 84 gallons, and to have 9 or 10 feet of its bottom surface

Fig. 201.

exposed to the fire; then he will find that he cannot turn more than about 6 or 7 gallons of water an hour into steam. By blowing the fire violently, this quantity may be exceeded, but with a great waste of coal: and it will require a very good chimney, with an excellent draught, to convert even 6 gallons of water an hour into steam, which is about the quantity required for an engine of one horse power; 6 gallons being nearly one cubic foot.

Suppose, then, a greater quantity of steam to be required; how is that to be obtained? The answer is this: only by a larger boiler and a larger fire, acting on a larger surface. This general statement must be understood in the following way.

A larger boiler, calculated to generate more steam, does not exactly mean one which holds more water. It is found that the power of the boiler depends primarily upon the extent of its exposure to the action of the fire, or, as it is generally designated, the extent of heating surface. It appears that the heat cannot penetrate through the material of the boiler with more than a certain rapidity, and that the water evaporated over each square foot by the heat passing through, is not more than about $\frac{5}{8}$ths of a gallon in an hour; and so it requires some 9 or 10 such feet of heating surface to boil off 6 gallons, or a cubic foot of water, capable of producing one horse power in the steam-engine. Now, for every such foot of heating surface there will be a corresponding generation of steam; and a boiler having 100 square feet of surface exposed to the fire will be capable of evaporating 100 times $\frac{5}{8}$ths of a gallon of water an hour, being 60 gallons, and about 10 horse power. The extent of heating surface, and not the quantity of fluid contained in it, is the measure of the power of a boiler.

One great object of improvements in boilers has been, to increase as much as possible the extent of heating surface without increasing its general dimensions. One very efficient mode of doing this, is by the adoption of internal flues. Thus Boulton and Watt have inserted a flue in the middle of the large waggon boiler, in the manner shown in figs 202 and 203; so that, after the flame has passed along the bottom of the boiler to the further end, it returns along the flue in the middle of the water to the front, and then makes an entire circuit of the outside of the boiler before entering the chimney. Thus, in a boiler 6 feet wide and 8 feet high and 20 feet long, an internal flue 3 feet wide and 3 feet deep, along the whole length, adds about 240 square feet of surface to the boiler, without increasing the bulk of the room taken up by it.

Fig. 202.

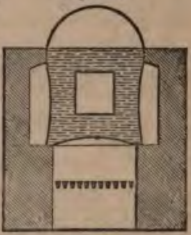
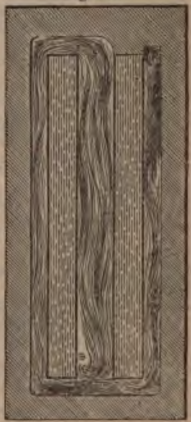


Fig. 203.



The same plan has been extensively employed in cylindrical boilers, the flame and hot air being made to traverse a hollow tube or cylinder in the interior of the boiler: sometimes several such flues have been used, and these multiflued boilers are now in great repute. Several modifications are given in the figures. The small internal pipes or cylindric flues, surrounded with water, traverse the whole length of the boiler, and expose a greater quantity of surface of water to the action of heat, in proportion as the tubes are small and numerous. These tubular-flued boilers are at present extensively used. They economize space, and, with a small exterior surface of boiler, generate a large quantity of steam. They are much used in Cornwall, and in marine and locomotive boilers.

Fig. 204.

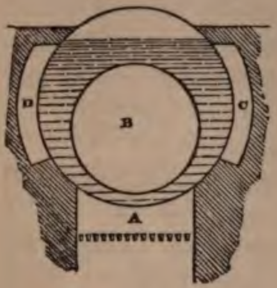
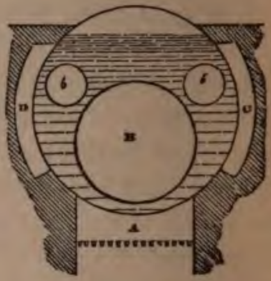


Fig. 205.



In these boilers a large surface is still exposed to the cold air, and the brick-work in which the fire is placed radiates off a considerable portion of heat, which is lost. To remedy this evil, the furnace has been so contrived that the fire is in the inside of the boiler. This was probably done for the first time by Smeaton, who succeeded in producing almost as high a proportion of steam from fuel as engineers of a more modern date. His portable-engine boiler is represented in figs. 206, 207. The interior of this hay-cock boiler contains a hollow ball of cast-iron, in which the fuel is burned. Air enters by an aperture at the bottom, a large cast-iron pipe leads through the water to the door, and another pipe in the opposite direction passes through the water, conducting the products of combustion to the chimney, immediately round which are introduced the fresh supplies of cold water for replenishing the boiler.

Fig. 206.

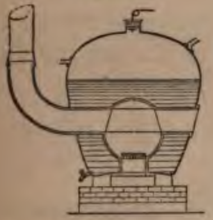
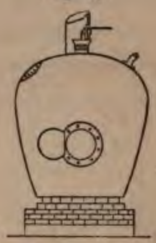


Fig. 207.



But a much better boiler than this, and one which indeed might bear comparison with many boilers of the present day, is given by Mr Farey as the invention of an unknown author. In the centre of a large old-fashioned hay-stack boiler, figs. 208, 209, is placed a large round furnace, from which there passes a simple rectangular flue, winding round and round the boiler in spiral circuits till it reaches the outside, and thence passes to the chimney.

Fig. 208.

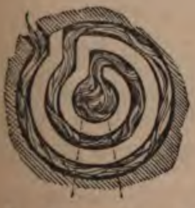
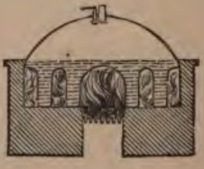


Fig. 209.



In the same way it has often been provided that the furnace should be in the interior of a cylindrical boiler, by placing another cylindrical tube of large dimensions in the interior of the outer case, as in fig. 210, to serve at once as furnace and flue. This was probably first done by Trevithick, the advocate of high-pressure engines in this country.

To the great central flue there have been sometimes added lateral flues on each side, for the return of the products of combustion, fig. 211. Thus, again, this internal flue has been made elliptical, fig. 212, a weak and therefore dangerous form.

Fig. 210.

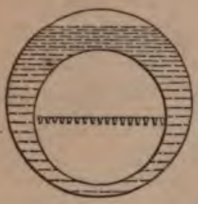


Fig. 211.

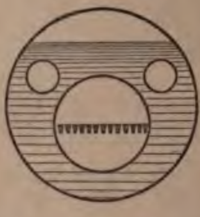
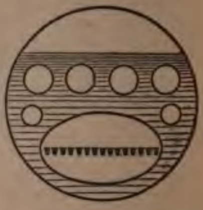


Fig. 212.



It is one of the faults of the boilers that have their fires in the internal tubes, that the ash-pit and interior of the furnace over the fuel are so confined, as to prevent that perfect combustion of fuel which may be obtained by a deep ash-pit, a large expanse of fire-grate, and a deep and wide furnace. These evils may, in some measure, be obviated by an internal flue of large dimensions; but this very large one is extremely dangerous, and liable to explosion. The evil has been remedied by the following species of boiler, figs. 213, 214, where the fire is still surrounded by water, and gives ample room for the most perfect combustion.

In this species of boiler, the tube opens out at the front, so as to leave a semicircle of a semi-cylinder above the fire, and two vertical spaces, or " water legs," as they are called, which cover the fire on both sides; thus obstructing the heat that would otherwise pass away into the brick building, and at the same time covering a large and wide space of furnace bars, a deep ash-pit, and so ensuring adequate combustion. The internal surface of this boiler has been still further increased, by substituting for this single tube a number of smaller ones, which in some cases are not more than two inches in diameter, as in figs. 215, 216.*

Fig. 213.

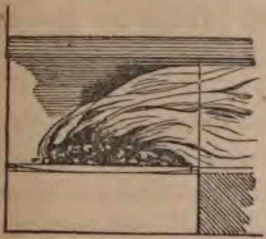


Fig. 214.

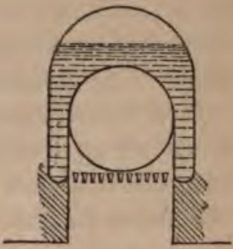


Fig. 215.

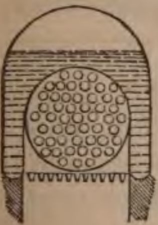
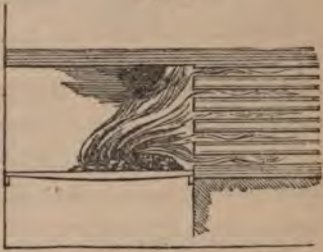


Fig. 216.



After passing through all these tubes, the flame and hot gases again return along the bottom and sides on the right of the boiler, and pass back on the other side to the chimney. The Butterly boiler, figs. 217, 218, and similar to this, is much used in Lancashire. It has the large internal flue, but wants the fire legs, and in this respect is inferior to the former.

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* Sometimes the small tubes are placed vertically in boilers, and in some varieties it is the water which occupies the tubes. Both copper and brass tubes have been employed in boilers; but owing to the improvements which are daily being made in the manufacture of iron and of iron tubes, it is likely that iron will soon come to be universally preferred. When from any casualty iron happens to be overheated, it is not so liable to become soft and to give way as copper or brass. When a boiler is made partly of iron and partly of any of these metals, the iron is liable to be seriously injured from galvanic action; but might be protected by means of zinc.

Those boilers, already described, are the practical forms in use among intelligent engineers. The varieties of boiler that have been invented amount to some hundreds. The Patent Records of the present day teem with new and improved boilers; and yet it is a matter of constant complaint that no great improvements are being made in boilers, but that as satisfactory results have been obtained from plain, simple boilers, of the kind used half a century ago, as from the modern and most complex forms.

Fig. 217.

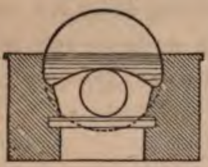
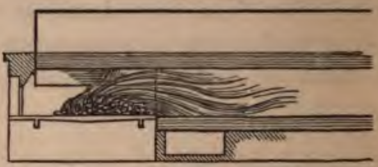


Fig. 218.



The conclusion to be drawn from all that has been attempted or achieved in boilers is, we believe, the following: that there exist certain limits prescribed by the constitution of fuel, the nature of metals, and the properties of water and steam, which cannot be exceeded without incurring evils that greatly overbalance the partial gain. The best boilers that have ever existed have been those in which a large number of principles have been applied, and so adjusted in relation to each other as to gain the maximum, not of any one property, but of all the valuable properties, each in the degree of its individual importance. The first cost of the boiler must not be rendered too great, for that would neutralize the economy of using it: the space to which it is confined may be as small as possible; but if that be produced by intricacy of construction, the loss may surpass the advantage. Then, again, if complex and confined, it may be impossible to cleanse or to repair the boiler; and therefore it must be remembered, that unless easy access can be gained to every part of a boiler, and of its flues, that boiler will soon become totally useless. Then it is further demanded of a good practical boiler, that, if one part should be damaged or give way, the whole should be so constructed that the damage done to that part must not endanger the rest. An extensive heating surface is to be obtained for economy's sake; but that large surface must at the same time remain unimpaired to resist bursting; a property to a certain extent inconsistent with extensive surface. The surface which is thus spread as widely as possible, so as to apply the fire to the water through every part of its mass minutely and in many subdivisions, if extended beyond a certain degree, will not have over it a body of water capable of conducting heat from it with the rapidity adequate to the rapid generation of steam, and to the preservation of the intensely heated metal from the destructive action of the fire. Then, again, it is desirable to have long and tortuous flues, to abstract as much heat as possible from the fuel and the products of combustion; but these, by their very length, may interfere with the draught of the chimney, so as to diminish the efficacy and vigour of the combustion of the fuel, and produce loss instead of gain. Thus it happens that the desideratum in boilers is an exact and judicious combination and adjustment of parts, so as to obtain each of these many points in that degree which is most advantageous for every one of the other qualities, and of all of them together. The question is a practical one of no common difficulty.

It is principally by the collection of facts, of accurately recorded statistics of boilers, of the practical experience of the most eminent engineers, that we can gather data for the solution of the question of the best boiler. We are not without such data, although it is much to be regretted that they are not more abundant. We shall now examine the various points in the structure and functions of a boiler in a simple succession.

The materials of which a boiler should be formed have been a subject much discussed. Copper, iron, brass, cast-iron, lead, and even stone, have been employed. Boilers of steam-vessels are frequently made of copper. Many steam-boilers have been made of cast-iron, and have lasted long, and been very efficient under careful management. Wrought-iron plate boilers are very common in this country; and in America have been much used, with cast-iron ends or heads of considerable thickness. The boilers of locomotive engines have the interior, which is exposed to the direct impact of the flame, formed of copper, and sometimes partly of brass; the exterior of the boiler being wrought-iron. Cast-iron boilers were extensively used under Mr Smeaton, towards the end of last century; and when used with care, were employed with advantage where fuel was plentiful, from their cheapness. A stone exterior jointed with cement, the interior being copper, where subject to great heat, and when the steam has scarcely any greater pressure than the atmosphere, has also been employed; and a dome or cupola of lead was often seen, in earlier times, when the art of working iron-plate was less common than it is now, forming the cover of the antiquated hay-stack boiler, which, in these times, the "waggon" of Watt has almost entirely superseded.

Copper is one of the best substances for steam-engine boilers, in a mechanical point of view. That it is not thought the best in a mercantile point of view, is proved by the almost universal use of wrought-iron boilers. Yet it is difficult to see why this should be the case, if we remember that copper generally lasts long, and is worth, when old, nearly two-thirds of its first cost, besides being a much better conductor of heat, and so saving fuel and space. The labour, too, of making a copper boiler is no greater than an iron one. The relative value of these materials for boilers may be stated thus :—

The efficiency of a copper boiler in generating steam is to that of iron as . .	3 to 2
The cheapness of equal weights of copper and iron boilers are as . . .	3 to 13
The value of old materials when not corroded, minus 15 years' interest, is .	4 to 3
Durability, ...	5 to 1
	30 to 13

The combination of all these ratios is in favour of copper; and if we add the trouble of more frequently renewing the iron boiler, and detaching it from all its connexions, the scale still further preponderates on the same side. We must look, therefore, for the explanation of the general use of iron to the state of mercantile affairs, and the value of money in a commercial community. It proves that a certain loss, within 15 or 20 years in a proportion of 12 to 1, is considered preferable to an original expenditure of four times the amount of capital; showing either that the price of money is too high for such an investment, or that the contingencies of mercantile life are too great to allow the risk of so large a sum as the value of a copper boiler for the period required to reimburse the proprietor. Rich governments and individuals have not failed to profit by this knowledge; but it may be noticed of a government which considers its tenure of office insecure, that it does not furnish even its war-steamers with copper boilers, as that would involve the expenditure of a large sum by which their successors would profit. So also the man who is shortened in means, but hopes to be rich enough by the time one boiler is done to get a new one; or who does not know how long he shall be solvent; or who, at any rate, cannot spare the money—procures at first the cheapest boiler he can; and finds, as usual, that in a short time the expenses of coal and of repairs have drawn from him a heavier than the usurer's percentage. All this applies more peculiarly to steam-vessels.

Another peculiarity of copper is the greater safety which arises from the uniformity of its texture. It is scarcely possible to account for the singular differences of sheets of iron that have passed nominally through the same processes of manufacture. One plate will become deteriorated by heat in half the time of another apparently identical. The parts of the same plate are frequently heterogeneous. The consequences of this heterogeneity are serious, and sometimes destructive: a single plate in a series gives way, and, having broken the chain of connexion, the whole fabric is destroyed; or a latent crack developes itself in the place most difficult to restore; or, one plate or a part of it is burnt through when all the rest remains sound. All this tells in favour of copper. The matter of the copper is very nearly homogeneous: its durability is nearly uniform if it is not made too thick. We have examined the part of a copper boiler exposed to most intense heat after years of action, and found, when the soot was cleared away, the smooth shining surface, produced by the rollers in the process of manufacture, remaining as perfect as the day after the boiler was started. In this case the metal was not more than one-eighth of an inch thick.*

There are some forms of boiler for which copper is less suitable than iron. The strength of copper to resist flexure is not nearly so great, especially at high temperatures, as that of iron. A copper boiler must therefore be well stayed, and if there be round, or any other unstayed flues in the boiler, they cannot be of more than a foot in diameter without incurring danger; they will readily collapse or bend. This caution in regard to copper being given, it may be unhesitatingly recommended in point of safety, durability, and ultimate economy.

In the treatise on STEAM,† we have already introduced our readers to the important experimental researches of the Commission of the Franklin Institute in America, concerning the structure, phenomena, and explosions of steam-boilers. Many other interesting particulars will be found in the details of their Report. But there is a branch of the investigation undertaken by the committee, which is of importance to our present enquiry. It regards the strength of materials of steam-boilers; a subject not before satisfactorily examined; and relates more immediately to the effect of high temperatures on the cohesive attraction of the particles of metals; an enquiry essential to our knowledge of the manner in which the strength of metal, when cold, may be altered when, in a boiler, it is exposed to a fierce fire. The sub-committee to whom this subject was intrusted, were men of great practical skill and eminent scientific attainments. Professor Walter R. Johnson, Benjamin Reeves, Esq., and Professor A. Dallas Bache, were the members to whom the enquiry was committed; and it has been carried on with a degree of judgment in its arrangements, and of precision in the experiments, which warrant our implicit confidence in the results, and deserve our sincere thanks for the valuable additions made to our knowledge of this important and difficult subject. The importance of the enquiry committed to these gentlemen may be judged of from the following statement of its principal branches.

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* On the other hand, it is alleged that copper boilers are very liable to be seriously corroded by sulphurous coal, and to suffer besides in the flues from the action of any salt in the water which happens to leak. It often happens that a small chink in an iron boiler will be gradually choked up by the rust; whereas in copper any tendency to leak continually increases.

† The articles Steam and Steam Navigation of the Encyclopædia Britannica have also been published together in a separate volume similar to this one.

1. What is the absolute tenacity of rolled boiler iron at ordinary temperatures, and how great the irregularities to which it is liable?

2. A similar determination for copper boiler plates.

3. What effect is produced on the tenacity of these boiler plates by change of temperature?

4. What is the effect produced on the tenacity of iron

by various processes of manufacture, such as wire-drawing, hammering, or rolling into bars or rods?

5. What are the comparative tenacities of boiler plate made from different mixtures of crude iron and from refined irons?

6. What is the comparative value of sheet iron manufactured by the processes of puddling, blowing, and piling respectively?

7. What is the effect of piling into the same slab, iron of different degrees of firmness?

8. What is the comparative tenacity of rolled iron in the longitudinal, diagonal, and transverse directions of the rolling respectively?

9. What is the influence of frequently repeated heating on the plates of a boiler?

10. What relation exists between the force that will produce a permanent elongation in boiler plate, and that which will entirely overcome its tenacity?

11. What amount of elongation may the several kinds of metallic plates undergo before fracture?

12. What is the effect of rivets on the strength of a boiler?

These are some of the many important subjects of experiment undertaken by the committee. They have discharged the duties devolved upon them in a manner which is highly honourable to themselves, and which reflects great credit on the institution and the country that has sent forth into the world so valuable a contribution to practical science. We regret that the limits of this treatise will not permit us to enter into the experimental details and subsidiary enquiries connected with the extensive and laborious investigation; details which are always ingenious and instructive, and will amply repay the minute study of the mechanical philosopher or engineer as a valuable body of experimental truth. But although we cannot convey to our readers the pleasure we have enjoyed in the perusal of these interesting records, we should do them and our subject injustice did we omit to convey to them the general conclusions which have been obtained.

Strength of Copper Boiler Plates.—The experiments upon this subject were very numerous. 32° being taken as the standard, it was found that the increments of heat always caused a diminution of strength. Thus, a stripe of copper, capable of carrying 10,000 lbs., was only capable of carrying 7500 lbs. when heated to a temperature of 500°; while at 820° the same bar could support no more than a tension of 5000 lbs., and at 1200°, a visibly red heat in day-light, no more than about a tenth part of the strength remains. By these experiments the law which connects the diminution of cohesion with the increase of temperature has been accurately determined, and it appears conformable to the following simple expression,

$$\left(\frac{t'}{t}\right)^3 = \left(\frac{d'}{d}\right)^2$$

whence

$$\text{Log. } d' = \frac{3}{2}(\text{Log. } t' - \text{Log. } t) \text{ Log. } d$$

by means of which the diminution of strength having been ascertained for one temperature, it may be found for every other according to the following rule. From the logarithm of (t') the temperature (reckoned from 32°) of the diminution sought, subtract the logarithm of a given temperature, (t) and multiply three halves of the remainder by the logarithm of the known diminution (*d*) of strength at the latter temperature, and the product is the logarithm of the required diminution at the temperature assigned.

The following table of the Diminution of Strength of Copper Boiler Plates when heated, exhibits the close accordance of the experiments with this law. Their standard strength at 32°, being 32,800 lbs. per square inch.

	Temperature above 32°.	Diminution of Strength.		Temperature above 32°.	Diminution of Strength.
1	90°	0.0175	9	660°	0.3425
2	180	0.0540	10	769	0.4398
3	270	0.0926	11	812	0.4944
4	360	0.1513	12	880	0.5581
5	450	0.2046	13	984	0.6691
6	460	0.2133	14	1000	0.6741
7	513	0.2446	15	1200	0.8861
8	529	0.2558	16	1300	1.0000

Thus the square of the diminution of strength varies with the cube of the temperature reckoned from 32°.

Hence we learn, that between the temperatures of freezing and boiling water, copper loses 5 per cent. of its strength; that at 550° it loses about a quarter of it; at 850° the half; and at 1330° it loses all its strength, becoming a viscid, granular, soft, incohesive, substance; although it does not actually melt until nearly at 2000°. These phenomena in copper are strikingly different from those exhibited by iron at the same temperatures.

In iron, the remarkable anomaly was discovered, that the additions of heat, instead of weakening the metal, as we should have expected, and as was found to be the case with copper, actually increased its strength, so that iron plate at 570° was 16 per cent. stronger than when cold. This point 570° was assumed as the standard temperature of maximum strength, because on both sides of it the strength was found to be diminished both by heat and cold: thus, per square inch, in round numbers,

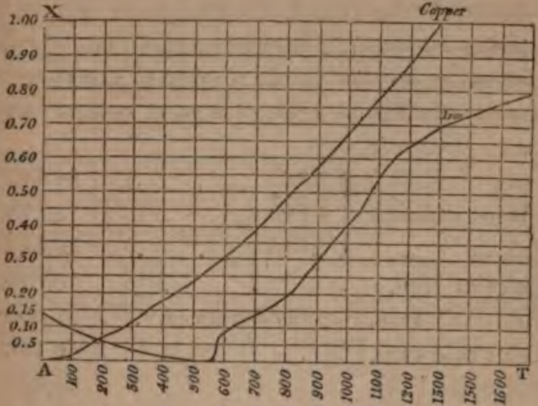
At 32° to 80° the tenacity was = 56,000 lbs., or 1-7th below its maximum.
At 570 — = 65,000 lbs., the maximum.
At 720 — = 55,000 lbs., the same nearly as at 32°.
At 1050 — = 32,000 lbs., nearly ½ of the maximum.
At 1240 — = 22,000 lbs., nearly 1-3d of the maximum.
At 1317 — = 19,000 lbs., nearly 3-10ths of the maximum.
At 3000 iron becomes a fluid.

The following table contains the results of a series of experiments on the tenacity of iron boiler-plate at high temperatures;

Temperature observed.	Tenacity observed.	Temperature observed.	Tenacity observed.
520°	58451 lbs.	824°	55892 lbs.
570	60398	932	45531
596	57682	947	42401
600	56938	1030	37587
630	60010	1111	27603
662	58182	1155	21967
722	54442	1159	25620
732	53378	1187	21913
734	57903	1237	21298
766	54819	1245	20703
770	54781	1317	18913

The law of variation of the strength of iron and of copper by temperature may be easily illustrated by the following curves, of which the horizontal ordinates are temperatures, and the vertical abscissæ are diminutions of strength.

Fig. 219.



The temperatures are measured from the origin A towards T. The total strength being = AX = 1, the diminutions of strength are represented by the fractions of A X measured from A towards X. These curves represent to the eye very distinctly the characteristics of the metals. The line for copper, rising from zero at A, shows, by continual recession from its maximum at A the continual and regular diminution of strength by increased temperature according to the law already stated. The line representing the iron, on the contrary, having its origin 15 per cent. above A, descends and shows an increase of strength until it reaches a maximum about 570°, whence it suddenly rises, showing a very rapid diminution of strength up to 1000°, when again it turns more outwards having a point of inflection beyond which it may be carried to a great distance, while at last it becomes liquid between 2000° and 3000°.

The next branch of the inquiry was, how the strength of iron is affected by the mode of its manufacture, and by the different states in which it is used, as in bars, in wire, or in plates, produced by hammering, drawing, or rolling. The following are the results of several experiments on the tenacity of different kinds of iron, at ordinary temperatures.

Iron Wire, diameter	0.333	84.186 lbs.
	0.190	73.888
	0.156	89.162
Russian Bar Iron,		76.069
English Cable Iron, hammer-hardened,		71.000
English Cable Iron,		59.105
Lancaster Co. U. S.		58.661
Centre Co. U. S.,		58.400
Swedish Bar,		58.184
Salisbury Com., U. S.,		58.009
Tennessee Bar, U. S.,		52.099
Slit Rods,		50.000
Missouri Bar Iron		47.909

No. 1. Pig iron of a white fracture produces the most cohesive bars.

No. 2. Pig iron of a lively gray fracture produces bars inferior to No. 1 by 1½ per cent.

No. 3. Pig iron of a dead gray fracture produces bars inferior to No. 1 by 2 to 3 per cent.

No. 4. Pig iron of a mottled fracture produces bars inferior to No. 1 by 5 per cent.

A mixture of all the kinds produces bars inferior to No. 1 by 5 to 10 per cent.

The difference between the strength of boiler-plate, cut lengthways and across, was found to be about 6 per cent. in favour of the longitudinal over the crosscut.

Stripes cut longitudinally sustained 63,947 lbs.
Stripes cut transversely sustained 60,176 lbs.
Stripes cut diagonally sustained 53,925 lbs.

The specific gravity of iron boiler-plate was found to range from 7.7922 to 7.6013, and to be at a mean value 7.7344.

The effect of repeated piling and welding was found to be a great increase on the strength of iron. The iron given in the preceding table, from the Centre Company's manufactory, whose strength when rolled amounts to 58,400, was found to be so much improved by piling four bars and welding twice, as to support a mean of 59,247 lbs. and to be so homogeneous that the highest did not differ from the lowest results by more than 3.4 per cent. in the different specimens. Simple welding twice without piling, gave a result of 58,787 lbs.

It has been thought that by welding together different kinds of iron of different degrees of fineness, and then rolling it out, a valuable boiler-plate might be obtained. This was tried, and the highest result gave only 40,600 lbs.

The weakening effect of riveting is thus calculated from these experiments, being a diminution on the whole of $\frac{1}{3}$d of the original strength.

Strength of the stripe without riveting, . .	9290
Strength of the remaining metal, deducting rivet-holes, ...	+ 5662
Diminution of strength by rivet-holes, .	— 3628
Strengthening effect of rivets, . .	+ 679

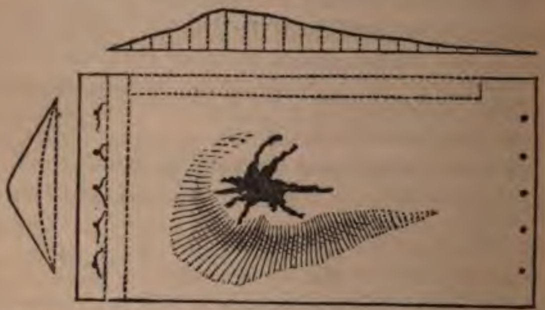
The effect of use and long exposure on the strength of boiler iron was found to be a great diminution of its strength, none of the specimens coming up to 50,000 lbs.

The effect produced by the accidental overheating of a boiler, was found to be the permanent reduction of its strength, from 64,000 or 65,000 lbs., to 45,000 lbs. per square inch, being about $\frac{1}{3}$d of the original strength.

The permanent extension produced on iron plate by weights much less than are required finally to overcome its cohesion, was a subject of careful examination. The extension began to take place in general when $\frac{3}{5}$ths, and sometimes when only $\frac{2}{5}$ths of the breaking weight were applied. The total extension varied between $\frac{1}{10}$th and $\frac{1}{16}$th of the total length, and was greater in the longitudinal than the transverse direction of the bar.

The following sketch of a fracture, fig. 220, is highly instructive. The elongation transversely is $\frac{1}{10}$th of the original dimension, and the curve is $\frac{1}{7}$th longer than the chord. The longitudinal direction of the fibres is in the line of the shortest dimension. It is evident that the diminution of the thickness, previously to fracture, must have greatly weakened the plates of the boiler. This plate was taken from that part of the boiler immediately over the fire, and had burst where sediment had collected, and excluded the water from contact with the boiler, so as to allow it to get overheated.*

Fig. 220.



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* Steam of high pressure, and in the expansive form, being now applied to almost every sort of purpose, renders the strength of boilers a subject of

It is evident that the diminution of area at the point of fracture, which accompanies this stretching of the plate before fracture, must weaken the plate very greatly when it is exposed to strains that stretch it much beyond its initial length, this strain being about half the breaking strain due to the original thickness. This constriction or thinning out of the plate is observed to take place much more in thickness than in breadth, and to amount in iron to about 16½ per cent. of the whole area. It is remarkable, that the constriction was found less in heated than in cold specimens of iron, a result the reverse of that which we should have anticipated. The fractures at high temperatures were found to take place suddenly, and the surfaces

very great and increasing importance. More numerous and varied experiments are certainly wanted on the explosion of boilers. It would, however, throw but little light on the subject to produce any ruptures by pressures increasing in a very slow and gradual manner: because in many of the accidental explosions, the force seems to have been as suddenly raised as in the explosion of a gaseous mixture, or in the blasting of rocks by gunpowder. It may, therefore, be a question, what confidence ought to be put in a lever safety valve? For when a great increase of force occurs instantaneously in a boiler, the strain is so very different from that of a steady pressure, that there is reason to fear that the resistance which a weight on a long lever opposes to its being instantly lifted, is greater than in the ratio of the simple distance of that weight from the fulcrum: so that a sudden increase of force which, being applied near the fulcrum, might not be able instantly to generate the excessive velocity which a prompt opening of the valve would require to take place in a weight at the extremity of a long lever, may be quite sufficient to burst the boiler.

Dr Lardner has lately suggested that explosions may be caused by lightning; but it is not easy to see by what process this could ever take place in such a massy metallic structure when not insulated. Granting that an explosive gaseous mixture did exist in a boiler, (which has never yet been known to be the fact,) the great mass of metal would so effectually conduct the electricity that it would have no occasion to dart through the mixture in the form of a spark so as to inflame it.

of fracture presented appearances altogether different from those exhibited at low temperatures; the peculiarity of the fracture at high temperatures being, that the section is smooth and flat instead of jagged, fibrous, and irregular, and that it takes place directly across the plate, and tapering off at an angle of 45°; so that the separate fragments resemble "the edges of two mortising chisels." One result which we deduce from the American investigation is, that boiler iron cannot safely be trusted with a greater pressure than ⅕th of its standard maximum cohesion. Such are some of the valuable facts elicited by this transatlantic investigation. The experiments should be repeated in this country upon the different species of our own iron; and we have no doubt the subject will be taken up by some of those gentlemen who have prosecuted valuable researches on the strength of metals; into which, however, they have not yet introduced the element of high temperature.

The increase of the strength of iron, with the increase of its temperature up to 570°, is a remarkable anomaly which should incite us to examine other metals and metallic alloys in a similar manner, for the purpose either of resolving this phenomenon into some general law of corpuscular force, or of setting it aside as a characteristic and distinctive property of that singular metal. To the practical man, this discovery is of importance, insomuch as it has shown him a quality in iron, as a material for boilers, which may weigh strongly with him when he hesitates in choosing.

The comparative value of copper and iron boilers is materially affected by this inquiry. The great advantages of copper are its durability, its high conducting power, and the value of the old materials. It is by no means so strong as iron, having when cold, $\frac{3}{5}$ths of the strength of iron, and at 500° only about $\frac{3}{8}$ths. But thin iron decays so rapidly, that its strength to-day is no criterion of its strength to-morrow : it decays so rapidly, especially with the salt water of steam vessels, that its very strength at first is necessarily followed with subsequent danger; for an iron boiler having once borne a great pressure with impunity, will afterwards, when the rapid but unseen decay has insidiously eaten through the metal, be again subjected to the same ordeal by which it had been formerly proved; and although under apparently the same circumstances, it may yield to the strain, and produce the distressing consequences of a violent explosion. It is time alone, then, that is the great enemy of iron boilers, while the integrity of the copper may continue unimpaired for a quarter of a century. On the whole we find that the following general result should limit our faith in the materials of boilers:—

Standard strength of boiler plate, .	55.000
Strength after riveting, . . .	$\frac{2}{3}$.
Strength after heating and cooling in use,	$\frac{2}{3}$.
Strain of permanent extension, . .	$\frac{2}{5}$.

Greatest practical strength $= \frac{2}{3}$ of $\frac{2}{3} + \frac{2}{5} = \frac{8}{45} = \frac{1}{6}$ nearly.

The greatest practical strength being $\frac{1}{6}$th of the absolute cohesion, and the greatest practical strength, to prevent explosion, being four times more than any boiler should be ordinarily worked at, we have $\frac{2}{45}$ or $\frac{1}{22}$ of the standard strength of boiler iron, as its ordinary working pressure; 2500 lbs. of extension on each square inch of cohesive action may, therefore, be assigned as the safe working strain of iron boilers.

To a steam-engine boiler many appendages have been contrived for facilitating the regulation of the supply of fuel or of water, the intensity of combustion, the elasticity of the steam. One of the most simple and essential of these is the water-gauge; which is of three kinds, the glass-gauge, stopcock-gauge, and float-gauge.

The glass-gauge is of two kinds, plane and tubular. A plane glass-gauge consists simply of a small window in a boiler, of very thick glass, inserted at the place up to which the water should rise in the boiler. The tubular glass-gauge is a small pipe of glass about half an inch in width of bore, and an inch and a quarter in thickness. It is placed on the outside of the boiler, and communicates at the top and bottom by stopcocks with the interior of the boiler; the higher stopcock enters the boiler among the steam, a little above the upper surface of the water, and the lower stopcock enters a little below the surface of the water, so that the water, standing in the glass tube on the same level with the water in the boiler, shows itself in the glass tube to the attendant. These two gauges are shown in the accompanying drawings.

Fig. 221.

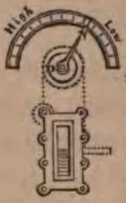


Fig. 222.

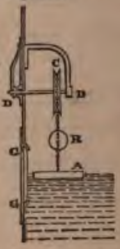
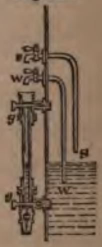


Fig. 223.

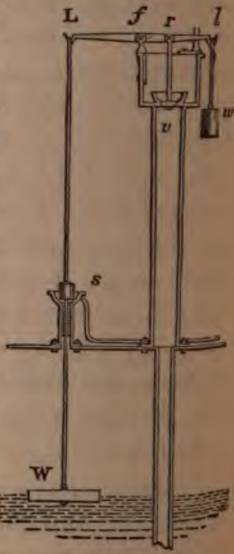


In figs. 221, 222, G is the window of very thick glass, set in a brass frame with a cement of red and white lead, after which, the frame is firmly bolted on the front of the boiler, at the aperture to which it is fitted. *gg*, fig. 223, is the tube glass-gauge, communicating with the water below and the steam above. There are shown in the same figure two other kinds of gauges. W*w* is a tube open at both ends, regulated at the external termination by a stopcock, but passing into the boiler, so that the other end descends below the surface of the water in the boiler. Another gauge-tube S*s* is of similar construction, and is placed higher up, so that the end S is open in the boiler among the steam. By this means the engineer has it always in his power, on opening these cocks successively, to determine whether there be an excess or deficiency of water in the boiler; for the orifices of the tubes in the inside of the boiler are adjusted in such manner, that when the water is at the proper lever, it covers the orifice of the lower one, but does not reach the orifice of the upper one. In this state steam will issue from the upper pipe, and water from the lower pipe; but if it should be found that water issues from both, the water is too high, and if steam from both, there is too little water in the boiler. Another species of gauge is also shown in figs. 222, 223. It consists of a float A resting on the surface of the water in the boiler: to this is attached a chain, which passes over a pulley C, and carries at its other end a counterweight R. The pulley is fixed on an axle DD, which passes through the boiler, and carries on its outer end an index. The index shows, by means of a dial-plate, the state of the water in the boiler.

By these means, a careful attendant may always ascertain the state of the water in the boiler, with sufficient ease to enable him to regulate the supply or the feed of the water required for the formation of steam. But if by any cause the attention of the keeper should be diverted from the state of the boiler, it will gradually be emptied, and will either be exploded or burned out, from being made red hot. Various contrivances have therefore been attempted for rendering boilers automatic; so that the very fact of the water becoming low in the boiler should of itself be the means of furnishing or admitting a fresh supply. The manner of accomplishing this is somewhat different in different circumstances; but the following methods are the most common and as yet the best.

A self-regulating feeding apparatus may be adapted to the boiler of a low-pressure steam-engine, in the following simple way. The water that is to feed the boiler is to be conducted into a reservoir *v r*, fig. 224, of some 18 inches diameter, having a long pipe to lead down from it to the bottom of the boiler. The top of this pipe is closed by a tapered plug which hangs by the rod *v r*, from a lever supported at *f*, and having two weights, one at each end, W and *w*. The larger weight W, of stone or cast iron, rests on the surface of the water in the boiler, and is counterpoised by the smaller weight *w* in such a manner, that W is partly sustained by the water; therefore, whenever the water in the boiler falls below the proper point, the weight W preponderates, the arm L of the lever is pulled down by the wire W L, which passes steam-

Fig. 224.



tight through a stuffing box at *s*, the end *l* of the lever ascends, and the valve *v* being withdrawn, allows the water to descend through the open end of the pipe, and replenish the boiler; and after a time, when the supply has become sufficient to raise the water to its proper level, the weight W, and the end L of the lever are raised, the opposite end *l* is depressed, and the valve *v* again closed, until a further supply has become necessary, when it is given again in the same manner.

This self-acting valve is sufficiently efficient when the boiler is of low pressure, or when the reservoir is more than two feet two inches high above the surface of the water for every pound of pressure per square inch of the boiler. But it very often happens that the boiler is fed with cold water in a different manner: a force pump is attached to the steam-engine, by which each stroke of the engine sends back into the boiler a quantity of water equivalent to that which has been evaporated out of the boiler in forming the volume of steam which has given to the engine motion through that stroke by which the pump has been impelled. Now, if the size of the pump were accurately proportioned, so as to replace in the boiler at each stroke the precise quantity of water evaporated from it in the same interval of time by the engine, it is evident that no further provision for adjustment would be necessary. This quantity is nearly one cubic inch of water for each cubic foot of atmospheric steam given to the engine, or one cubic foot = six gallons per horse power per hour. But the evaporation of the water to a steam-engine is not thus uniform, nor so easily determined. The variations of intensity in the fire cause steam more or less dense to pass over into the engine; the steam now raises the safety-valve and escapes into the air, and now falls below the standard; the boiler, now tight, and again allowing water and steam to leak through its joints, wastes a greater or a less quantity of steam; and thus, even with this automatic supply, there is required a regulating or governing power. A stopcock is attached to a pipe by which the feed-pump obtains its supply of water to force into the boiler, and so, by impeding or facilitating the passage of the water into the boiler, the attendant may regulate the supply. We have said that this cock is attached to the pipe by which the pump obtains its supply of water, and not to the pipe by which the same pump forces its contents into the boiler it is about to supply; and we have done so for this reason, that it is dangerous to apply such a stopcock on the pipe between the pump and the boiler, because, if the force-pump become once filled with water, and be forced down by the engine when the stopcock is wholly or nearly closed, the pipe will be burst from the incompressibility of the water, unless its valves should be so leaky as to allow the water to pass back into the reservoir from which it has been withdrawn. As, however, it is sometimes desirable to have the regulating cock on the boiler feed-pipe, the following provision is made to render that method of regulation safe and efficient. Between the feed-pump and the boiler, fig. 225, there is inserted, in connection with the feed-pipe F,

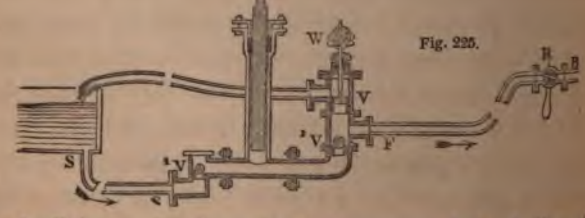
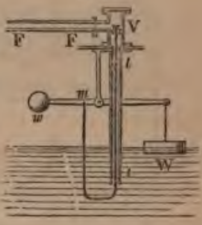


Fig. 225.

at any point V beyond the valve of the pump V^2 which prevents the return of the water into the pump, a loaded escape-valve V; its load W being so adjusted, that whenever the regulating stopcock R is turned so as to impede the passage of water towards the boiler B, the force of the feed-pump pushes the water up against the loaded valve V, and by it escapes through the return pipe above into the reservoir of supply S, again to be brought back into the pump when required for the future supply of the boiler.

Still, however, this apparatus depends in some measure on the adjustment of the regulator-valve R by an attendant; and contrivances have been invented to render this also automatic. In the boiler, and on the surface of the water, is placed a weight W, with a partial counterpoise *w*, so as to rest on the surface of the water. From the point *m* a small rod passes downwards and up again, through the feed-pipe L *l* to the point V, where a conical valve or plug V opens the communication with the feed-pipe F F and the water of the boiler when it is raised, and shuts it again when depressed. Now, when the water is abundant, the weight W floats high, and keeps down *m* and V; and when low, W descends, and raising *m* and V, admits the required supply into the boiler without any assistance.

Fig. 226.



Where a high-pressure boiler is used for purposes in which a steam-engine is not employed, detached self-acting feeding apparatus must be employed. The following elegant and most effective apparatus has been invented by Mr Macdowall of Johnstown, and is now extensively used in Scotland. We have seen it in an efficient working state, after being employed for many years, and it only costs about £20. It is nothing less than a small steam-engine, but it is applied in a most effective and simple way to the purpose designed.

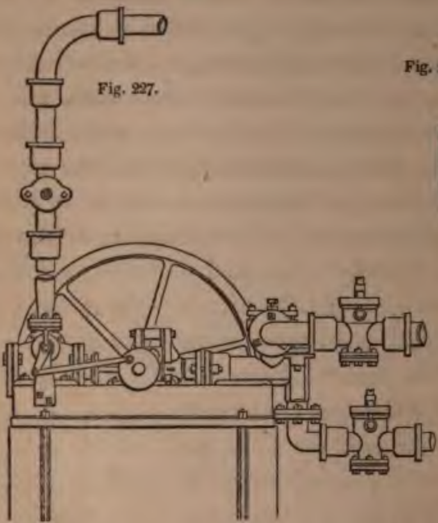


Fig. 227.

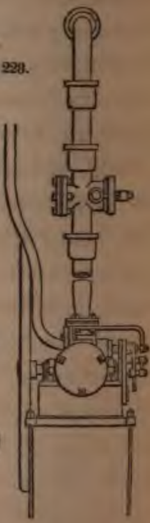


Fig. 228.

A very simple apparatus on a similar principle was adapted some years ago to feed a boiler without the assistance of a steam-engine. A close vessel or reservoir is placed above the level of the boiler, and is in communication with the water in the boiler through one pipe, and with the water to be supplied to the boiler through another; a third small pipe connects the steam-chest of the boiler with the top of the said reservoir. All these pipes being closed by moveable regulators or stopcocks, the attendant is first to open the steam communication, that the reservoir may be emptied of air and filled with steam, and the stopcock is then shut. In the next place, the communication with the cold water to be supplied is opened, and the reservoir on getting cool becomes vacuous, so that the pressure of the atmosphere fills it with cold water, and the communication is then cut off. Lastly, the third stopcock is opened, and the water in the reservoir having free communication with the water in the boiler, it is only necessary to open the steam-cock again, and the water, being in equilibrium by the pressure of the steam, will run freely by its own pressure, from its height above the boiler, into it, and the process of alternately filling and emptying the boiler may be repeated as often as required by turning the cocks in this succession. A simple process renders all these valves self-acting.

Fig. 229.

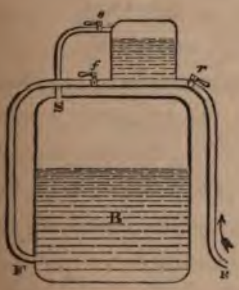
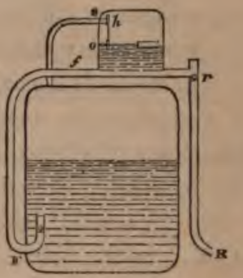


Fig. 230.



The reservoir, fig. 229, is a close vessel above the boiler B; R *r* is the pipe by which the cold water is obtained, and it is regulated by the stopcock *r;* F *f* is the feed-pipe for the boiler, regulated by the stopcock *f;* S *s* is the steam-pipe, opened by the stopcock *s*. In fig. 230, there is a balanced float on a pivot *o*, and a slit bar *h* connecting a small slide-valve *s* with a pin on the float bar; *r* is a common ball valve, acting only upwards; and in F is a valve permitting the descent of the water in the pipe F *f*, and preventing its return. The latter is of the self-acting form, of which the action once begun will continue indefinitely. A commanding valve being connected with the boiler-float, would render the play of this apparatus dependent on the requirements of the boiler itself. The reader who is acquainted with the steam-engine of Savery will perceive at once that this reservoir, with its apparatus, is a mere Savery's steam-engine, applied to pump water into the steam boiler; and that this application of that engine is not liable to the objection urged against it in other circumstances, namely, that the water is heated as well as raised. In this instance, the heating is attended with no loss.

Indices of pressure and safety apparatus are important appendages to a boiler. These are of four kinds; dynamometers, safety-valves, fusible plugs, and alarms.

The usual dynamometer, to measure the force of steam, is a simple tube, bent upwards at the end, and formed sometimes of glass and often of iron. The two ends of this tube being curved up, so as to give it the form of the letter U, one of these extremities is applied to the boiler, and placed in communication with the steam; mercury is poured into the tube, so as to fill one-half of it, and the pressure of the steam upon one of the extremities of the column of mercury, forces the mercury to ascend in the other, and to indicate, on a divided scale, the amount of pressure, which is about one pound on the inch for each inch of height on the scale. It is necessary,

Fig. 231.

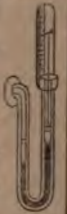


Fig. 232.

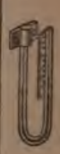
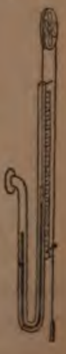


Fig. 233.



in all these mercurial gauges, that the tube be of equal diameter throughout its length. If the tube be of iron instead of glass, it is necessary that a float of wood, or iron, or ivory, figure 231, resting on the top of it, should ascend above the tube, and indicate on a scale the place of the mercury. For high-pressure boilers, a longer tube and scale are, of course, necessary; and a very convenient form for this purpose is given in figure 233. From a float resting on the fluid stretches a string carrying a counterpoise at the other end, and passing over a pulley, raises or depresses the index of a valve on which the pounds of pressure are indicated by the inches of the scale.

Another very convenient index of pressure, preferable to any other with which we are acquainted, is the piston-gauge. A tube of small diameter, two or three inches, is bored truly cylindrical, and attached to the steam chest of the boiler, figure 234. This cylinder has a solid plug or piston truly turned, and ground exactly, but not loosely, into it. The pressure of the steam bearing up the piston on the lever, one end of which is attached to the spring indicator, gives the true indication of the pressure on the piston. The spring is also applied directly above the pis-

Fig. 234.

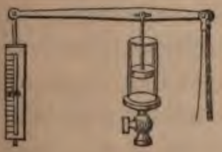
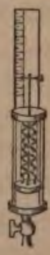


Fig. 235.



ton, as shown in the second figure; but this instrument is used on a smaller scale than the other. The ordinary safety-valves are described in another part of this treatise.

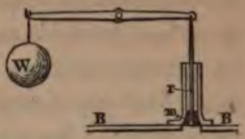
There is a species of safety boiler apparatus in which great faith has been placed by many mechanicians and men of science. It has been proposed and enacted that boilers be furnished with fusible plugs, or that, in parts of a boiler exposed to high temperature or pressure, there should be placed plugs, forming small parts of the boiler; which plugs being composed of metals easily melted, shall give way when by accident too great pressure and heat have been employed, and so, by a less evil, prevent the greater one of total disruption of the boiler. This method of creating a less evil to avoid a greater has lately been shown to be fallacious, and ought to be abandoned. For the complete exposure of the inadequacy of the system of *rodelles fusibles* or fusible plugs, we are indebted to the Committee of the Franklin Institute, already so often named with gratitude. The American experimenters found, that when alloys of tin, lead, and bismuth are applied to steam boilers in the way recommended by the Commission des Rodelles Fusibles, the alloy does not melt in the manner of an homogeneous metal, as has been supposed; but that, in fact, the more fusible metal melts in the minute cells of the less fusible metal, long before the whole mass becomes liquid; that the minutely divided, but more obdurate metal, forms a grating, or rather sponge, in which the other lies melted, so that when the temperature of the steam rises to melt the first metal, the pressure of the steam gradually expels the one metal out of the meshes of the other unmelted metal in globules, in such a manner, that the plate at last consists merely of the one unmelted metal, the other having, by repeated heatings, completely exuded from it, and been replaced by such particles of debris as the water of a boiler in common use always supplies in abundance. Thus, a plate of two metals, originally designed to give way at 250°, may still deceive the unconscious attendant, and withhold its warning till it have reached a temperature of 500°, and contain a combination of heat and water as dangerous as gunpowder, and greatly more treacherous.

The following experiment will illustrate the whole of this enquiry. A plate of alloyed metals, of which the melting point in the crucible was about 260°, was submitted to heat under pressure. Such a plate would be applied to a boiler, of which the temperature was not designed ever to exceed in the most extreme case one atmosphere, and of which the usual working pressure would not be more than 5 or 10 lbs. It was found that at 256° small particles of melted metal began to exude from the cells of the unmelted metal; the globules thus driven out were carefully examined, and found to be fusible at 222°. At 260° a second portion exuded, and their dross were found to melt by themselves at 232°. At 270° the remaining metal was still tenacious, and was not burst until the steam reached a temperature of nearly 300°, with an explosive force of three times that at which it should have given warning by fusion, and the escape of water and steam, from the small aperture it had filled. This last residual porous plate of metal was found not to melt until it reached the temperature of 345° instead of 260°. "These experiments the Committee (properly enough) deem conclusive, in regard to the use of fusible plates in the ordinary way; and they conceive that substituting fusible plugs of greater thickness, say half an inch, as has been directed by a recent ordinance in France, would not serve as a remedy to the defect thus exposed."

The true remedy for this evil was the next object of the enquiries of this excellent Committee. They properly inferred, that the fusion of an alloy of metals at a given temperature was only to be depended on when it was not exposed to the mechanical action of steam, that is, when not exposed to its pressure, but only to its temperature. "The true remedy is to be sought in enclosing the fusible metal in a case, in which it shall not be exposed to the pressure of the steam; so that the more fluid parts of the metal shall not be exposed to being forced out of the mass, but the whole become fluid, as if exposed to heat in a crucible." With this view of the subject, trial was made of an apparatus described by Professor Bache, in the Journal of the Franklin Institute for October 1832, under the title of "An Alarm to be applied to Steam Boilers."

The construction of Professor Bache's alarm is sufficiently simple. "A tube of iron or copper, according to the material of the boiler, and closed at the lower end, passes through the top of the boiler, its closed end reaching the flue to which it is attached. This tube, it will be observed, affords a ready access to the flue to ascertain its temperature, without any restraint from packing. A mass of fusible metal placed at the bottom of the tube will become fluid very nearly as soon as the flue takes the temperature of its fusion. To show when the metal at the bottom of the tube becomes fluid, a stone is attached with a cord and weight, or with a lever and weight. The weight and longer arm of the line, descending, may be made to ring a bell or turn a cock, or open a valve, permitting just enough of steam to issue, to give the alarm. A projection on the

Fig. 236.



lower end of the rod prevents it from being drawn from the metal until this latter is fused, and by widening the lower part of the tube the metal is kept from being drawn out by the rod. BB, fig. 236, is part of the boiler plate; *m* the fusible metal in a tube; *r* the rod to which it is, as it were, soldered, and when the metal melts, the weight W will descend and give the alarm, either by striking a bell, opening a steam whistle or trumpet, or raising a valve. This apparatus of Professor Bache's is a valuable addition to the mechanism of steam.

Fig. 237.

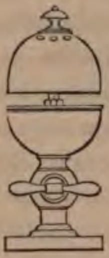
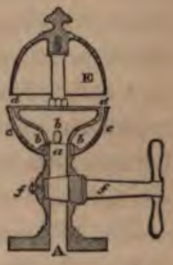


Fig. 238.



The common alarms, the steam whistle and the steam trumpet, may be made to give noisy indications of an excessive pressure of steam. A small box on the steam chest is to cover a lock-up safety-valve, loaded at the highest pressure the boiler should endure. On this box is to be placed a steam whistle or a steam trumpet, so that an alarming noise will be the consequence of any excessive pressure; for the steam issuing through the aperture of the instrument will give it voice with an intensity proportioned to the pressure.

In figs. 237, 238, a steam whistle is represented. A *a* is a tube leading from the boiler: in it is a stopcock. On the top of the tube is a hollow piece *bb*, surrounded by a thin cup *cc*, and carrying, by a pillar fixed on its top, another inverted cup E. When the stopcock is opened the steam enters the cup *cc* through holes in the foot of the hollow piece *bb*, and rushing out at the narrow orifice *dd*, between the cup *c* and the hollow piece, strikes on the edge of the cup E, and produces an exceedingly loud and shrill sound. No stopcock is, of course, required when this alarm is placed on the box of a safety-valve, in the manner stated above.

On the Proportions of Boilers.—That a boiler when constructed shall be capable of generating a sufficient quantity of steam, without burning an excessive quantity of fuel, without incurring an excessive expense in construction, and without endangering the durability of the metal, subject to the intense heat of the fire, is a problem of some difficulty, especially when it is attempted to obtain a maximum of effect at a minimum of means, whether the minimum desired be that of weight, bulk, or expense. There are some simple rules deducible from the best practical results that have come under our examination.

The quantity of water to be evaporated in a common steam-engine is generally reckoned at one cubic foot an hour for each horse power. But if allowance be made for accidental leakage of the boiler, for blowing off at the safety-valves, for priming, and other casualties, an addition of one-fifth part may be provided for. The standard for calculating is, however, one cubic foot of water for each horse power.

The area of the grating in the furnace on which the fuel is laid is an important element of efficiency in a steam-engine boiler. Here practice somewhat varies. The bars are generally about one inch broad on the top, and the interstices from $\frac{1}{4}$ to $\frac{1}{2}$ an inch wide. These apertures supply oxygen to the fuel, and regulate the combustion, which is only perfect when the supply of air is ample. It is found that as much air as will pass through each square foot of the area of the grate of the fire is sufficient for the effectual combustion of as much fuel as will, in a proper boiler, evaporate one cubic foot of water an hour, and supply one horse power in a steam-engine. Thus, a fire grate 6 feet square, containing $6 \times 6 = 36$ square feet, is found to give an ample supply of air for the combustion of as much fuel as will supply an engine of 36 horse-power, evaporating 36 cubic feet of water an hour. But although this is a safe and excellent proportion for ordinary practice, yet it has been found, that with a quick draught a smaller extent of fire surface is sufficient. So low a proportion of fire grate as ⅔ds and even ½ of a square foot to each horse power, has been employed by eminent engineers, and has succeeded, while others recommend a much larger allowance even than one square foot. It is certain that the larger area of fire-grate is conducive to economy and durability. The standard of surface is, therefore, to be taken at the most desirable proportion, and only to be deviated from where limited space, as in locomotive-engine and steam-ship boilers, renders this rule inapplicable. This standard is one square foot of area of grate for each horse power.

The next condition on which the success of the boiler problem depends, is the extent of the surface of the boiler acted on by the fire, so as to apply its heat to the water. This is also a subject on which practice varies widely; so widely indeed as from 8 to 36 square feet per horse power. Eight feet require a clean thin copper boiler, and a very direct impact of the hottest part of the flame, with the loss of a portion of the heat; but 36 feet, on the contrary, imply the possession of profuse space, and a desire to economise to the very utmost the powers of the fuel. The standard of practical effect with the usual iron boilers, in ordinary circumstances, is 15 square feet of heating surface for each horse power.

Of this surface, about one-third is horizontal, and two-thirds are vertical surface; and of these, the horizontal surface is imagined to be twice as effective as the vertical surface. Arguing on this supposition, some have given it as a rule to calculate *each vertical foot as only half an effective foot* of heating surface, and so to make nine or ten square feet of effective heating surface the standard of boiler power. But this rule, though giving the same result as the former, proceeds on a supposition not yet established, and which does not always coincide with the fact. It will be easily seen that 5 feet of horizontal surface, added to 10 feet of vertical surface, making, according to the one mode of calculation, 15 feet of surface, divided in the proportion of two-thirds vertical and one-third horizontal surface, forms an exact equivalent to the other mode—of reckoning the 10 feet of vertical surface only equal to 5 effective feet of surface, and adding to the said 5 effective feet of surface the 5 feet of horizontal surface, making in all 10 feet called effective feet of heating surface.

The next essential consideration is the area of the chimney and flues. It has already been given as a standard, that the fire grate should have the area of one square foot for each horse power. Now, this area for the admission of air should be accompanied with a sufficient passage to carry off the gaseous products, and the hot air and flame resulting from combustion. From an examination of the best boilers, it appears to us decided that one-fifth of the area of the fire grate, gradually diminishing to a chimney, which shall have one-tenth of the area of the fire grate, is an excellent proportion. We therefore feel disposed to recommend it as a standard for steam-engine boilers: one-fifth, diminished at the chimney to one-tenth part of the area of fire grate.

The chimney should be of the same diameter throughout its interior; and if of 40 feet height and one-tenth part of the area of the fire grate, it will give an abundant draught. If the height of the chimney be greater than this, the area may be diminished as the square root of the height is increased.

The quantity of water to be contained in a boiler is a matter of some importance. If we consider bulk and weight as of no consequence, and if the boiler be in constant work, there cannot, perhaps, be too much water. On the contrary, if there be only a small quantity, many evils are encountered. In the first place, a large mass of water serves to regulate the production of steam from a boiler, much in the same way as a fly-wheel regulates the speed of an engine; whereas with a small charge of water, the unavoidable oscillations that happen in the supply of cold water or the additions to the fire, make sudden and injurious changes in the production of steam. In the next place, it is well known that steam is a very bad conductor of heat, and has a small capacity in its gaseous state for the acquisition of more heat. Hence it is found that if the production of steam be rapid, and the water present in a smaller proportion, the heat is not carried off sufficiently fast from the metal heated by the fire, the boiler is overheated and rapidly deteriorates, while the production of steam is greatly retarded. For these reasons, it is necessary to have a large supply of water. Eight to thirteen cubic feet are very commonly allowed by practical men. As a standard, or perhaps as a minimum, we may assign ten cubic feet of water in the boiler, in its mean condition, for each horse power. In like manner, we will do well not to leave less room in a boiler for the steam than is assigned for the water.

Economy of Fuel in Steam Boilers.—The ordinary consumption of fuel by one of Mr Watt's engines is 10 lbs. of coal for each horse power every hour. The work done by this fuel is equivalent to the power of raising 150 lbs. 220 feet high in a minute, or of raising 220 times 150, that is 33,000 lbs. one foot high, or any equal product of mass by height in every minute, by the combustion of 10 lbs. of coal, which gives in every hour 198,000 lbs., raised one foot high, by the combustion of one lb. of coal. This, however, by care and economy, is often exceeded by Mr Watt's engines; and the following are about the standards of work done at a given expenditure of fuel in ordinary engines, which is called the Duty of Steam-Engines.

The Duty performed by Ordinary Steam-Engines is—

One horse power exerted by 10 lbs. of coal an hour.

Quarter of a million of lbs. raised one foot high by one lb. of coal.

Twenty millions of lbs. raised one foot by each bushel of coals.

The constant aim of engineers is to increase the amount of this duty; in other words, to make less than 10 lbs. of coal do the work of one horse, or to obtain a greater duty than a quarter of a million of lbs. from one lb. of coal, or more than 20 millions of duty from a bushel, or 84 lbs. of coal. To such an extent has this effort been successful, that one cubic foot of water has been converted into steam capable of exerting one horse power by the combustion of less than 5 lbs. of coal; and this steam has been so managed in the engine as to raise one million of lbs. one foot high by one lb. of coal, and in one case 125 millions of lbs. by a bushel of coals was the duty obtained in Cornwall. Of these improvements part is due to the economy of steam in the engine itself,* and does not come under this head. That part, however, which is the result of economy in the boilers deserves our attention here.

By a series of experiments, carefully conducted or collected, and ably discussed, by Mr Parkes of Warwick, the statistics of steam-engine boilers have been placed in an aspect sufficiently clear to enable us to deduce some general results of considerable economic importance. The particulars will be found in the large table at the end of the volume. The observations were made upon three great classes of boilers; the Cornish high-pressure boiler, I. to IV.; the waggon boiler and common low-pressure boiler, V. to XIV.; and the locomotive-engine boiler, XV. and XVI. The waggon boiler, V., was treated at Warwick in a peculiar manner by Mr Parkes himself, who is the advocate of a peculiar system of management, by which very slow combustion of the fuel is produced.

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* This chiefly consists in using steam of high pressure expansively: such as giving it a pressure of 40 or 50 lbs. above the atmosphere, and cutting it off at from one-third to one-twelfth of the stroke. In the Cornish engines, too, the outer casing or jacket is still retained; although that is now discarded in many other engines, notwithstanding its being more needed than formerly, on account of the higher temperature.

Under the articles Hygrometry and Thermometer of the Encyclopædia Britannica, it has been shown necessarily to follow from admitted principles that, under a constant pressure, air expands in geometrical progression for equal increments of heat. More recently Professor Faraday has drawn the same conclusion as regards elastic fluids generally, from his very valuable and extensive experimental researches on heat. This conclusion, while it gives great encouragement to employing steam of high temperature and pressure, and receives confirmation from the advantages which result from so using it, is fatal to the host of mathematical investigations founded on the gratuitous assumption, that under a constant pressure the expansions of elastic fluids are simply proportional to the increments of heat.

The Cornish boilers, I. to IV., are distinguished from the common boilers, both in construction and treatment. The surface which they expose to the fire is enormous, being four or five times as great as the standard of usual practice, as we find in I., where 34 horse power has a surface of 2600 feet, and in II., where 48 horse-power has a surface of 3170 feet exposed to the fire. This species of boiler is invariably cylindrical, and traversed longitudinally by cylindrical iron flues. It is also surrounded by external flues, except on the upper surface, which is placed under a roof, and enclosed to a considerable depth in sawdust, or other non-conducting matter. The circuit which the flame and hot gases perform, in contact with the flues, is about 150 feet long. The treatment of the Cornish boiler is as peculiar as its structure; for, instead of a strong draught, a tall chimney, and an intense fire, the fuel is laid on in large masses; it is allowed to cake and to consume very slowly, while its products pass up the chimney, after having paid a leisurely visit to the two or three thousand feet of absorbent heating surface that surround its long and circuitous passage towards the open air. Very perfect combustion is obtained by the thorough combination of the oxygen, and the ample time permitted for the communication of the heat thus developed. Durability in the materials, economy in the fuel, and increase of useful effect, are obtained by the Cornish construction and usage, to an extent that excels every other mode of generating steam with which we are acquainted.

The economy of the Cornish boiler and its causes may be estimated by comparison with the standards we have already given of very ordinary practice.

CONDITIONS.	ORDINARY STANDARD.	CORNISH BOILER.
Area of fire grate in square feet	1	2
Area of heating surface in do.	15	60 to 70
Circuit of heat	60 ft.	150 ft.
RESULTS.		
Coal per horse power per hour	10 lbs.	5¼ lbs.
Coal consumed per hour per foot of grate	10 lbs.	2⅝ lbs.
Water evaporated by each lb. of coal	6 lbs.	11⅘ lbs.

The few selections from the valuable magazine of practical facts presented in this table, serve to show how much is to be gained, even without the assistance of new inventions, by judicious construction and treatment of ascertained and practical kinds of boilers and ordinary fuel. A saving of 50 per cent. over ordinary practice is gained in Cornwall by large fire grates, thick fires, slow combustion, internal flues, extensive fire surface, and external coverings. He who desires to improve the construction or management of his boilers has only to fulfil the conditions that are now brought under his attention.

The common waggon boiler stands contrasted in all points with the Cornish boiler. Yet it is cheering to see how much advantage may be gained by a judicious construction of fire grates, and a proper system in managing the fire, as is shown in Mr Parkes's experiments on his boiler at Warwick. The only peculiarities of the Warwick treatment appear to have been a large fire grate, 1¾ square feet to the horse power, and slow combustion; the high result of 10 lbs. of water evaporated by each pound of coal, and the economical result of only 6 lbs. of coal to each H.P. per hour, appear as the reward of this treatment.

The locomotive-engine boiler is in every point contrasted with the Cornish boiler. To pursue this part of the investigation more minutely than its exhibition in the tables, would not coincide with the objects of this section. It partly belongs to the article Railways of the Encyclopædia Britannica, which has also been published in a separate volume. Indeed most of the improvements connected with steam which have taken place since the publication of the first edition are more closely related to Railways and Steam Navigation.

Erratum, page 146. A sentence should begin with line five from bottom. That a mere weight, &c.

N. B. If the crank be too long, it may move so fast that a weight could not act properly upon it while descending; but this can always be avoided by using a shorter crank. Perhaps it would tend to soften the action of the weight, if something slightly elastic were interposed between it and the crank. It is evident that, in some cases to suit want of room, a weight might be made to act nearly as well if raised on a rod far enough above the crank as hanging down under it.

The want of the fly in Mr Lucy's engine (page 147) must have been partly supplied by some other means than anything there described, unless it were the momentum of the millstones. Because the pneumatic pump provides no increase of force at the commencement of each stroke to overcome the inertia of the great beam, and of other parts of the machinery having a corresponding reciprocating motion. As little does it provide any cessation of force near the end of the stroke, so as to allow the acquired momentum of those reciprocating parts to be exhausted in propelling the machinery, that they may come to rest without any waste of power.

DESCRIPTION OF THE PLATES.

Plate I. Figs. 1 and 2 exhibit a front and side elevation of one of the simplest forms of the non-condensing steam-engine. Its principal parts are the cylinder A, the piston-rod P *p*, and connecting rod *p* K, acting directly upon the crank K X, and fly-wheel W W. There are also an eccentric and valve-rod *x x x*, and governor *w w*. Two columns and an entablature support one extremity of the crank axle, and give attachment to minor appendages. The other extremity of the axle rests on the wall of the building. To the columns is attached *g g*, a guide for the top of the piston-rod. The feed pump *f f f* is worked by another eccentric on the crank shaft.

Figs. 3 and 4 exhibit an engine of still greater mathematical simplicity than the last, although its mechanical arrangements are probably more intricate. No member intervenes between the piston-rod and crank. A double cross-head H H, which is carried by the piston-rod P *p*, has an oblong open space in the middle in which the crank pin, in its circle of rotation, oscillates freely on alternate sides of the piston-rod; and this cross-head, being itself powerfully confined to move in the vertical direction only, by the slides on the columns *m m* of the framing, the vertical motion of the piston-rod is precluded from having any other dynamical effect than the most direct of all possible conversions of rectilineal into rotatory motion. The other letters refer to the same parts as in the last figure.

Plate II. Figs. 1 and 2 show the high-pressure engine in its most improved form for stationary purposes. It is analogous, in the arrangement of its principal parts,

to the usual construction of Boulton and Watt's condensing engine. A cast-iron base supporting six columns and an entablature, forms a framing upon which the parts of the engine are distributed, so as to form what is called a portable engine, being entirely independent of the building in which it may happen to be placed. At one extremity of the base is placed the cylinder A A, and at the other the crank-axle X, and fly-wheel W W. The motion is transferred from the piston P *p*, through the great lever L L L, and connecting rod or crank rod L K. The feed pump *f f* is in this instance worked from the point *m* of the parallel motion, in the way generally adopted in condensing engines for working the air-pump, whose place in fact it here occupies. The valve is a short D-slide, worked by eccentric gear, *x x x x*. S is the steam-pipe. The eduction pipes E, E are seen descending on both sides of the valve casing; they unite in a common chamber beneath the cylinder, whence a pipe conveys the educted steam to the chimney, or to serve some other purpose, as the case may be. The governor acts as in the previous case. This drawing is taken from the form of engine manufactured by Messrs Caird and Company.

Figs. 3 and 4 exhibit a form of the upright condensing engine manufactured by Messrs Carmichael of Dundee, and successfully applied by them to various purposes. It is compact and has been found to work well.

The cylinder A is placed upon the floor, and on each side of it stands a cast-iron column. These columns being hollow are used as steam-pipes, S S, S S, to convey the steam to the jacket of the cylinder, from which it finds its way into the valve-chest D. On the top of the columns is a cross-beam sustaining the crank axle, and the columns support guides *m m*, *m m*, on which, by means of wheels *g*, *g*, and a cross-head *g p g*, the piston-rod P *p* is maintained in its vertical position, so that the connecting rod *p* K is directly attached to the crank-pin K. The air-pump G is worked from the crank-shaft by means of a second crank or bend, and an eccentric *x x* works directly the slide valve; *f f* is the feed-pump for the boiler, worked directly from the air-pump cross-head; *w w w w* is the governor, with its appendages; C is the condenser; N the cold well.

Plate III. Fig. 1 is a sectional elevation of a land-engine of twenty-five inch cylinder and five feet stroke; and fig. 2 is its horizontal section at the level of the base of the cylinder; A is the cylinder, P the piston, P*p* the piston-rod, B*b* the parallel motion, L L L the great lever. The pillow blocks L*l*, in which the centre of the great lever works, rest on the spring beam UU, whose ends are secured to the walls of the building in the manner shown on the next plate. The centre of the spring beam is sustained by the columns VV and their entablature *u*, which crosses the building and has its ends secured to the walls like those of the spring beams. At the other end of the great lever are the connecting rod L K, the crank K X, and fly-wheel WW. Returning to the cylinder we have D, D the slide-valves and their casing; *d*, *d* the packing ports. The valve-casing terminates below in E E the eduction-pipe leading into the condenser C. G is the air-pump, F the place of the foot-valve, *h* the air-pump piston-rod. The condenser and air-pump with their appendages are placed in the cold well N. M is the hot well, into which the contents of the air-pump are discharged, and from which the hot water pump *m* draws its supply

by the pipe m'. The pipe oo leads from the hot water pump for the supply of the boiler. The cold well is supplied from the cold water pump n by the pipe $n\ n'$. The rods for working the hot and cold water pumps hang from a stud at each side of the lever at m. The governor ww is supported on a bracket tt, which bridges across the main shaft. The influence of the governor is conveyed to the throttle-valve by the levers and connecting rods ww, ww. The valves are worked by the eccentric $x\,x\,x\,x$, ff is the eccentric shaft which carries the gab-lever f', on which the eccentric rod acts; it also carries the levers for working the side rods of the valves, the levers which carry the counterbalance weight, and the socket for the starting lever. The small pillars T, T, which surround the cylinder, are surmounted by an entablature which serves as a support for a gangway round the cylinder.

Plate IV. represents in detail the different parts of the engine just described, separated from each other, in order more clearly to exhibit their construction. Figs. A, A′, a, a' show the details of the cylinder. In A, A′ is shown the upper and lower ports of the cylinder at 1 and 2, and the steam port at 3. In A′, 4 is the cylinder cover, 5 the stuffing box, a is an horizontal section of the cylinder, and plan of the cylinder cover.

Figs. D, D′, d, d' show the slide-valve casing; D a front view, D′ a side view, 1 and 1 are the packing ports, 2 and 2 the packing-port covers, 3 the eduction pipe, d the cover of the slide valve casing, 4 its stuffing-box, d' a section of the casing. Figs. C, G, F, show a side elevation of the condenser, foot-valve, and air-pump; C′, G′, F′, a section of these; and c, g, f, a plan of them. 1 is the cover of the foot-valve, 2 and 3 a section and front view of the valve. Fig. L shows a side view of the great lever, L 1 a top view, and L 2 a transverse section through the centre of it. Figs. K, K′ show a front view and section of the crank. Figs. X, X, *x* show a side view, an end view, and a plan of the crank shaft pillow block. Figs. *l*, *l* 1, *l* 2, show a side view, an end view, and a plan of the pillow block for the main centre of the great lever. Figs. *m*, *m*′ show a vertical and horizontal section of the hot water pump, and figs. *n*, *n*′ of the cold water pump. Figs. B 1, 2, 3 are the details of the main links of the parallel motion; *b* 4, 5, 6, 7, 8 details of its air-pump links; 9, 10, 11, 12 side and top views of its radius and parallel bars. 13, 14 is the clutch for the top of piston-rod; 15, 16, the gudgeon and clutch for the top of air-pump rod; 17, 18, top and side views of the ring gudgeon to which the parallel rods are attached; *p* piston-rod, H air-pump piston-rod, *h* air-pump rod, *g g* cold water pump-rod and piston-rod, and *g*′, *g* hot water pump-rod and piston-rod, *x* the eccentric, WW, 1, 2, 3, 4 details of the fly-wheel, O main centre or gudgeon for the great lever; P, P′ 1 plan and section of the piston, *w*, *w*′ 1, 2, 3, 4, 5 details of the governor, *w* the spindle, *w*′ the slide, 1, 1 the radius arms to which the balls 5, 5 are attached, 2, 2 the radius arms which cause the balls to act on the sliding collar *w*′, 3 and 4 the stay for confining the motion of the balls. *t* 1, 2 is the slide-valve rod and side rods, *t* 3 is the slide-valve cross-head, R, R′ a side and front view of the connecting rod.

Plate V. exhibits a sectional elevation of a condensing engine designed by Mr M‘Naught of Glasgow, and extensively applied by him to cotton, silk, and saw-mills. The principal peculiarity in its structure is the arrangement by which no further masonry is required for its foundation than the building in which it stands, the usual cold well being dispensed with, and the whole structure being connected by cast-iron beams with the walls of the house. The cylinder AA is attached immediately to TT, the cast-iron beams of the floor, which are deeply bedded in the wall at T and T, and it rests directly upon the large vessel C, which forms the condenser, and is supported likewise by beams YY, which are bedded in the walls. The condensation is effected by injection alone, without the usual accompaniment of a cold well around the condenser, an appendage that may safely be regarded as by no means indispensable to the practical perfection of the vacuum—when the vessel itself is formed with few joints. The transverse beams of the buildings are supported by two pillars directly under the centre of the great lever LLL, so as to support the main centre L; and the crank-axle X and the axis Z of the fly-wheel W, are supported on UU, another beam of cast-iron.

The steam enters the house through the pipe SS, passes round the cylinder to SS, around the long slide-valve DD, being confined to the middle of it by the valve packing *hh*, and after performing its duty in the cylinder, passes out at EEE into the condenser C, where it is finally condensed into water. Hence it is drawn off at the foot-valve F by the piston H of the air-pump G, and delivered by the discharge-valve M into N, the hot well. The slide-valve DD is worked by the eccentric gear *xxxx* and the rod *d*D through a moveable stuffing-box *dx*.

Plate VI. and VII. represent the high-pressure engines which work the inclined plane at the Liverpool station on the Liverpool and Manchester Railway. They are beautiful and in many respects highly judicious; they are the work of Messrs Mather, Dixon, and Co., Liverpool.

WWW, Plate VIII. is the great wheel which works the rope that draws the railway train up the inclined plane; the rope is contained in a groove in the edge of the wheel. A clutch *kk* connects or disconnects the crank-axle XXX with the wheel WW; the cranks KX, KX, KX are placed at right angles, so that when one is on the centre the other is at the furthest distance from it. K*k*, the connecting-rod, hangs down from L, L, the ends of the levers. The centre of the side levers, Plate VI., rests on a truss at no greater height than three feet above the floor of the engine-room. L*p* is a side rod by which the levers are united to the cross-head *rpr*. The steam in this instance comes about a quarter of a mile from the boilers to the cylinders AA by the steam-pipe SSS. Fig. 2 is a section of the steam-valves and cylinder. The valves DD are short D-slides, surrounded by steam, and by the underside of the valves the escape takes place through the space E; *d*D is the valve-rod moved by the usual valve-gear *xxx*. The eccentric *xxx*, Plate VI., is placed on a long shaft from the crank axle at X, which shaft is also employed to work the governor-balls *ww*. The whole foundations are solid red sandstone rock, in which excavations are made for the shafts and ropes.

Plates IX. X. and XI. These two very beautiful engines, constructed by Mr Fairbairn of Manchester, are the property of Messrs Bailey and Co. of Staley Bridge, near Manchester. They drive a cotton mill, and possess many excellent adaptations to this purpose.

These engines are of a similar form to those employed in large steam-vessels, and will serve very well to conduct the student from the common to the marine engine. The working beam or great ever LLL, is, as it were, split in two, one of the halves being placed on each side of the engine, but united at the middle by a large gudgeon or main-centre LL, and at the one end by a cross-head, L*p*L, and side rods, RL and RL, and at the other end by a cross-tail of similar form, and the connecting rod KL, which turns the crank KX. The moving mass is thus placed lower, and the whole rendered more compact than the common house engine.

This double marine engine is reckoned preferable in the manufacture of cotton to an engine of the common kind. The double engine gives a considerable degree of uniformity to the velocity produced; and the approximation to uniformity is rendered still more perfect by the short stroke, in which the variations of force recur at shorter intervals than with a long stroke. A striking peculiarity in this pair of engines is the large fly-wheel, WWW, formed of toothed segments, which receives the moving force of both engines, and gives it out directly, and with a high velocity, to the mill shafts YY. Not only is the requisite speed of revolution attained very readily and quickly by this means but the momentum of the wheel is immediately conveyed to the shaft, instead of passing through a series of wheel and axle work. The durability and excellence of this arrangement are unquestionable.

The section, plate IX. shows the details of many of the parts. The steam-pipe SSS from the boiler conducts the steam into a space SS, forming a jacket round the cylinder AA. The piston P has metallic rings on its periphery as packing; U and V the upper and lower steam-ports are wholly formed in the cover and bottom plate of the cylinder, and are closed and opened alternately by two short D-slides in two separate valve-chests above and below. The steam enters the upper chest from the jacket at S, where the throttle valve is inserted and passes through the valve. The packing on the back of the valve is screwed down from above by a vertical spindle, and the eduction takes place through E by a hollow vertical column on one side of the valve-chest, while the steam passes down to the lower port through another column. The condenser C is a single casting, placed immediately below the valve-chest, and is entered by the injection pipe *cc* at *c*, of which the aperture is regulated by a slide-valve and vertical spindle ending in a screw. F is the foot-valve, governing the communication between the condenser and air-pump G; H is the air-pump piston, with common clack valves; and M is the delivery valve, opening outwards into the hot well. The waste pipe is immediately below M; and the feed pump and pipe *f* are in the masonry below the lever, so as to draw the feed water from the waste pipe.

The valves DD receive motion by an apparatus somewhat peculiar. A stud in the crank pin K carries round a small radius rod *x x* on an axis, concentric with the crank; a smaller crank on this axis or shaft has a length equal to half the throw of the valve, or equal to that which would be given to the usual eccentric, and by a bar *x x* similar to the eccentric rod, the valve is moved by this lesser crank, just as by an eccentric. This gearing has the advantage of lightness and precision, *m m m* are the usual links of the parallel motion; *d* is a counterpoise to the weight of the valve, *w w* are the weights of the governor.

Plates XII. XIII. XIV. exhibit views of a pair of beautiful marine engines, constructed by Mr Napier, for the four British and North American royal mail steam-ships Britannia, Acadia, Caledonia, and Columbia, plying between Liverpool, Halifax, (Nova Scotia,) and Boston, (U.S.) The following are the general dimensions of the vessels and engines.

	Ft.	in.
Length from figure-head to taffrail, .	228	
Length of keel and fore-rake, . .	206	
Breadth of beam between paddles, .	34	6
Depth of hold, ...	22	6
Diameter of paddle-wheel, . .	28	
Length of floats, . . .	26	
Diameter of cylinder, . . .	6	
Length of stroke, . . .	6	10

These engines have about 240 horse-powers. The paddle shafts make 16 revolutions per minute. The tonnage of the vessel by the old law is about 1200 tons.

Plate XII. is a side elevation of one of the engines.

Plate XIII. is the elevation of the crank end of the engines, and Plate XIV. the elevation of the cylinder end. By an inspection of these engravings it will be seen, that the parts of the engines are sustained by an elegant and rigid Gothic framing, rendering them, notwithstanding the ponderosity of their different parts, entirely independent of the vessel on which they are placed. AA are the cylinders, B the slide-valve casing, C the condenser, D the hot well and air-vessel placed on the top of the condenser. E the air-pump, FF the feed pumps. The moving parts of the engine are as follow:—K the cylinder piston-rod, I the crosshead, H the cylinder side rods descending to the great side levers GGG. Connected with the parts last described are the radius rods of the parallel motion L, the motion side rod L′, and the parallel motion shaft *l*, V the valve or weigh-shaft on which is fixed the valve lever W, whose other end is inserted into a clutch on the slide-valve link *c*. On either side of the centre of the great lever depends a side rod *f f*, to work the bilge and brine pumps, and to its extremity are attached the links of the cross-tail of the connecting rods, P the links, Q the cross-tail, R the connecting rod. To the upper end of the connecting rod is attached the crank S; T is the intermediate or crank shaft, T′ T′ the paddle-wheel shafts. On the crank-shaft is placed the eccentric U; and *uu* is the eccentric rod working the eccentric gab-lever *v* on the valve or weigh-shaft $t\ t^2$. Y *y y* the expansion valve apparatus, *h*, *h* escape valves at top and bottom of cylinders, X paddle wheels, *k* lever for starting the engines, 1, 1 steam-pipes, 2, 2 waste water pipes from hot well, 3 double force-pump for filling boilers, extinguishing fires, and washing decks, 4, 4 engine beams, 5 5, 5 5 midship section of vessel, 6, 6 thick planks checked in upon and bolted through the timbers thus:—

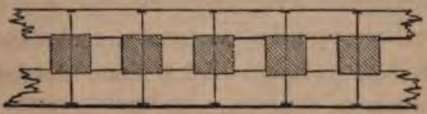

Plate XV. This is one of that class called the rotatory steam-engine; a class comprehending many varieties of which we hear much and see but little. The engine is given as an illustration of this very unsuccessful class of engines, by one of its least exceptionable examples. It has actually been in use for some years, being frequently employed to turn the machinery of a large establishment.

We have seen it working smoothly and well: yet we have not been able to recognise in it any reason for giving it an equality, much less a preference, in comparison with the common engine. It can be reversed in the same way as a common engine. It was invented by Mr Yule of Glasgow, by whom it was patented, and is still in the works of the late Thomas Edington, Esq., at Glasgow.

SSS is a double steam pipe, either branch of which may be employed according as the engine is to go forward or backward. AA is the cylinder firmly fixed on a stone foundation, and in its centre is an axis XX, upon one side of which, and eccentric to the cylinder, is an inner cylinder or barrel turned quite true, and fixed to revolve with the axis X, and so to form the piston P, which is to receive and give out the force of the steam. RR furnishes the *point d'appui*, or surface of reaction, which resists the force of the steam and forms a fixed obstacle. It is a flat slide or sluice, (see fig. 5), resting on the barrel piston P, and maintained by guides always in a vertical position. It passes into the cylinder through a rectangular stuffing box, and is raised and depressed by a small eccentric pin *x x*, so as to remain always upon the surface of the piston drum. All the working surfaces are rendered steam-tight by metallic packings. EEE is the eduction passage into the condenser or the open air, DD are slide valves to be reversed when the engine is to go backwards. On the revolving axis of the piston X are toothed wheels, G, G, working other two, G, G, which have a common axis *zz*, carrying a fly-wheel WW, and driving the machinery to be worked by the engine. Fig. 6 shows the ports at D, D. Fig. 7 shows the guides of the slide RR.

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ERS.

		PARTICULARS OF THE EVAPORATION OF WATER AT THE TEMPERATURE OF 212°.				PARTICULARS OF THE PROPORTIONS OF HEATED SURFACE TO FUEL BURNT AND WATER EVAPORATED.					
Place of experiment.	Nature of coals used.	Pounds evaporated by 1 lb. of fuel.	Pounds of fuel evaporating one cubic foot of water.	Pounds of water evaporated by the products of combustion per square foot of grate per hour.	Pounds of water evaporated per square foot of heated surface per hour.	Square feet of heated surface to one square foot of grate.	Square feet of heated surface per lb. of fuel burnt per hour.	Square feet of heated surface per lb. of water evaporated per hour from its initial temperature.	Square feet of heated surface per lb. of water evaporated per hour from 212°.	Square feet of heated surface per cubic foot of water evaporated per hour from its initial temp.	Square feet of heated surface per cubic foot of water evaporated per hour from 212°.
		lbs.	lbs.	lbs.	lbs.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.	sq. ft.
Cornwall. uel Towan	*W	11.89	5.25	33.66	0.932	36.11	12.75	1.205	1.072	74.67	67.04
nited Mines	W.	11.76	5.31	48.13	1.096	43.88	10.72	1.022	0.911	63.94	56.98
ean of exp. I. and II.	W.	11.82	5.28	40.89	1.014	39.99	11.73	1.113	0.991	69.30	62.01
ast Crinnis	W.	...	...	...	...	66.66	9·52	...	...	...	...
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arwick	S.	10.32	6.05	41.28	6.396	6.45	1.61	0.1759	0.1563	10.99	9.77
ithero............	L.	6.73	9.27	77.69	4.273	18.18	1.57	0.275	0.234	17.25	14.63
Ditto.	L.	9.79	6.38	78.55	4.970	15.80	1.97	0.236	0.201	14.80	12.57
eston.............	L.	8.56	7.28	85.44	8.000	10.70	1.07	0.143	0.124	9.00	7.82
Ditto..	L.	9.67	6.46	89.77	8.388	10.70	1·15	0.135	0.119	8.48	7.45
Ditto.	L.	9.60	6.50	114.13	10.663	10.70	0.900	0.107	0.093	6.71	5.86
bion Mills......	N.	9.63	6.48	158.55	7.448	21.28	1.294	0.150	0.134	9.38	8.39
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Ditto.	N.	9.09	6.87	59.75	7.015	8.51	1.379	0.159	0.142	10.00	8.91
ean of exp. VI.—XIV.	L. N.	8.86	7.15	95.50	7.166	13.88	1.315	0.171	0.149	10.77	9.39
ong Benton	N.	8.37	7.46	170.36	13.02	13.08	0.642	0.0816	0.0767	5.10	4.79
anchester & Liverpool Railway......	Coals	7.21	8.66	573.25	12.04	47.59	0.581	0.096	0.080	6.02	5.03
llingworth. ...	Coke	5.17	12.07	235.50	24.48	9.61	0.211	0.047	0.040	2.95	2.55
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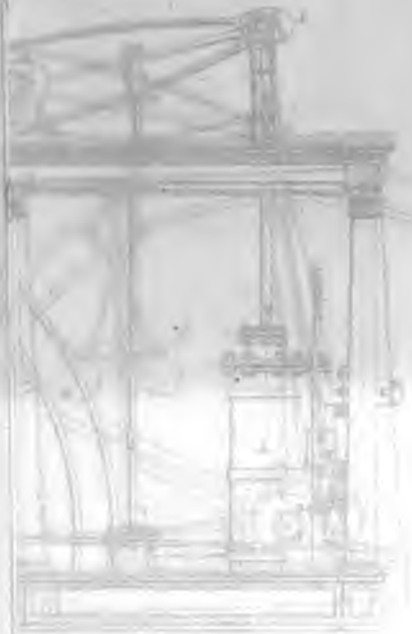

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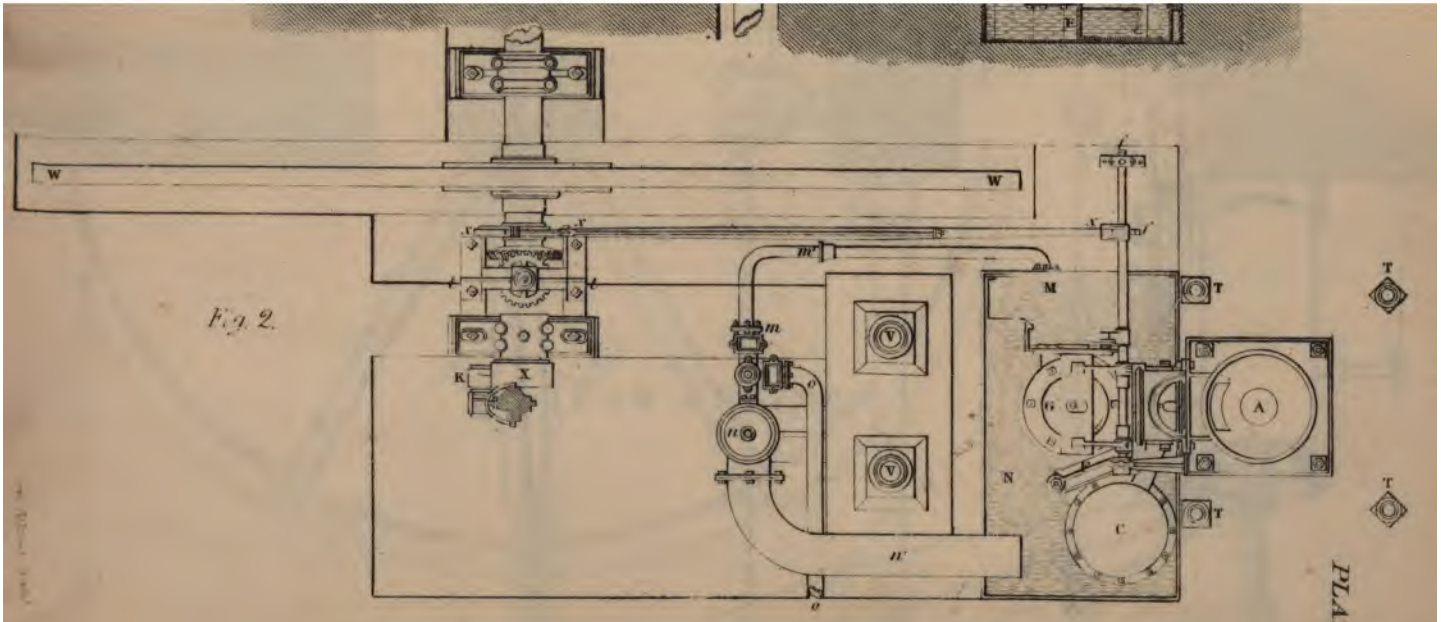

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